Evaluation of Systems for Measuring Employee Exposure to Ultrasonic Sound at

Company XYZ

by

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ABSTRACT

Workers exposure to ultrasonic sound was evaluated using Type 1 and Type 2 personal noise dosimeters and real-time analyzers (RTA). There was no statistically significant difference between employee exposures measured using Type 1 versus Type 2 dosimeters. Several exposures were above the OSHA Hearing Conservation and the ACGIH TLV criteria, but none were above the OSHA Engineering criteria. Numerous one-third octave band ultrasonic frequency measurements recorded by the RTA exceeded the ACGIH ceiling criteria for ultrasonic sound.

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Chapter I: Statement of the Problem

Noise is an area of concern in the occupational setting and has been for centuries (National Institute for Occupational Safety & Health, 1998; Sataloff R. and Sataloff, J., 2006, p.1). Written regulations of noise exposure in the United States began in 1948 with the U.S. Air Force Regulation (AFR) 160-3, "Precautionary Measures Against Noise Hazards" (Paul, K. 2006). In 1969 the American Conference of Governmental Industrial Hygienists (ACGIH) established initial threshold limit value (TLV) recommendations for occupational noise exposure (ACGIH, 2006).

In 1970, the federal government wrote the Occupational Safety and Health Act, Public Law 91-596, in order to provide safe and healthful work conditions for United States employees (Occupational Safety and Health Act of 1970, 1970). Section 7 of the Act established the National Institute for Occupational Safety and Health (NIOSH) to aid in developing appropriate recommendations for occupational hazards. NIOSH (1972) published "A Recommendation for Occupational Exposure to Noise" that focused on the prevention of hearing loss. The Occupational Noise Exposure Standard 29 CFR 1910.95 lists the permissible exposure limit (PEL) for general industry noise as 90 dBA based on an 8 hour time-weighted average (TWA) (Department of Labor, 1971). OSHA amended the noise standard (1983) to include a hearing conservation program for employees exposed above an average of 85 dBA for 8 hours (Department of Labor, 1983). OSHA's Technical Manual addresses a type of noise known as airborne ultrasonic noise (U.S. DOL, 2008). Ultrasonic noise sometimes is inaudible to the human ear due to its high frequency, yet is capable of producing hearing loss and other adverse health effects (Berger, 1996; Crabtree & Behar, 2000; Fulmer, M., 2001; Hanson, C., 2001; Howard, C., Hansen, C.H., Zander, A.C., 2005; Lawton, B.W., 2001; McLaughlin, D., 2001;

NIOSH, 1998; Pawlaczyk-Luszczynska, M., Dudarewicz, A., Sliwinska-Kowalska, M.,2007; U.S. DOL, 2008; Wiemiki, C. & Karoly, W., 1985) .

1.1 Statement of the Problem

Ultrasonic noise emitted from ultrasonic welders used at Company XYZ causes noise exposure to the operators of the welders. This study sought to evaluate systems for measuring high-frequency noise and associated subharmonics experienced by the welders.

1.2 Purpose of the Study

The purpose of this study was to evaluate the effectiveness of Type 1 and Type 2 noise dosimeters for monitoring employee exposure to ultrasound emitted from ultrasonic welders.

1.3 Objectives of the Study

The objectives of this study were to:

- Determine the range of sound-pressure level exposures experienced by workers using ultrasonic equipment as measured by Type 1 and Type 2 noise dosimeters.
- Compare the sound-pressure level measurements from the Type 1 and Type 2 noise dosimeters to current OSHA regulations and ACGIH guidelines.
- Assess different types of instruments for evaluating ultrasonic noise.
- Investigate the association between the ultrasonic sound intensity and the type of components being welded.
- Discuss the applicability of using the proposed sampling method in other industrial settings exposed to ultrasound.

1.4 Background and Significance

This study is significant for the following reasons:

- It provided information on employee noise exposure during the use of ultrasonic welders. This information helped to determine if operators were being overexposed to noise based on the OSHA PELs and ACGIH TLVs.
- It explored the use of different measuring techniques that would be most effective in the detection of ultrasound. This will allow other companies to use proper sampling protocols to determine employee exposure to ultrasound.

1.5 Limitations of the Study

The limitations of the study are as follows:

- The measurement of ultrasonic noise was not evaluated for all possible types of joining components. Exposures may vary with the size and shape of the materials being welded together.
- The research conducted measured ultrasonic noise exposure due to ultrasonic welding at 20 kHz at one facility. Differences due to the facility layout and ultrasonic noise sources were not evaluated.

1.6 Definition of Terms

Exchange rate. An increase of decibels that requires the halving of exposure time or a decrease of decibels that requires the doubling of exposure time (NIOSH, 1998).

Hazardous noise. Noise loud enough to harm hearing (U.S. Department of Defense, 2007).

Impulsive noise. Noise characterized by a sharp rise and rapid decay in sound levels and is less than 1 sec. in duration (NIOSH, 1998).

LAVG. Average sound level measured over the run time for dosimeter measurements compiled using the 5 dB exchange rate algorithm (Quest Technologies Inc., 2005)

Leq. Average sound level measured over the run time for dosimeter measurements compiled using the 3 dB exchange rate algorithm (Quest Technologies Inc., 2005).

Noise. Unwanted sound which may be hazardous to health, interferes with communication, or is disturbing (Hirschorn, M. 1989).

Noise-induced permanent threshold shift. Permanent loss in hearing sensitivity due to the destruction of sensory cells in the inner ear. For purposes of this document, it refers noise-induced hearing loss (U.S. DOL, 2008).

Noise-induced temporary threshold shift. Temporary loss in hearing sensitivity (U.S. DOL, 2008).

Noise injuries. Loss of hearing either permanent or temporary.

Occupational diseases. Work-related health conditions.

Octave band analyzer. Sound level meter that divides noise into its frequency components to determine the frequency (ies) at which the noise level is hazardous (OSHA, 2007).

Personal noise dosimeter. A device that is worn by the employee during the workshift or sampling period used for measuring sound levels to determine personal noise dose. Dosimeters must meet ANSI S1.25-1991 requirements (U.S. DOL, 2008).

Sound level meter. General instrument used to determine noise levels that can be used to spot-check noise dosimeter performance, determine an employee's noise dose, identify and evaluate individual noise sources for abatement purposes, aid in determining feasibility for engineering controls, or evaluate hearing protection (U.S. DOL, 2008).

Sound- pressure level. Measurement of air vibrations that make up sound referenced to a standard pressure corresponding to the threshold of hearing at 1,000 Hz (WHO, 1999).

Threshold limit value. Refers to the airborne concentration of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects (American Conference of Governmental Industrial Hygienists, 2008).

1.7 Summary

OSHA has developed regulatory permissible exposure limits and the ACGIH has developed threshold limit values which define permitted levels for noise exposure based on the duration of the exposure. If the proposed noise levels are exceeded, employees may experience work-related hearing loss. In order for noise exposure to be properly assessed, noise instruments meeting the appropriate specifications must be used. The determination of the appropriate instrument and parameters used to measure sound is dependent on the characteristics of the noise being evaluated.

Chapter II: Literature Review

Work-related hearing loss is one of the most common occupational diseases in the United States (NIOSH, 2008). According to the U.S Bureau of Labor Statistics (2005) hearing loss accounted for 11.4% of all nonfatal occupational illnesses in the year 2004 followed by respiratory conditions (7.1%) and poisoning (1.3%). Although skin disease (15.6%) and other occupational illnesses (64.6%) accounted for the most nonfatal occupational diseases in the year 2004, these categories included a much broader range of possible occupational illnesses. To date, it has been estimated that 30 million employees are exposed to hazardous noise each day, which has resulted in approximately 10 million workers with permanent hearing loss (NIOSH, 2008). Industries at high risk for worker noise exposure are: agriculture, mining, construction, manufacturing and utilities, transportation, and military (Concha-Barrientos, M., Campbell-Lendrum, D., & Steenland, K, 2004; NIOSH, 2008). The manufacturing industry alone reported nearly 84% of all hearing loss cases in the United Sates in 2004 (U.S. BOL Statistics, 2005).

In 1995, it was estimated that 120 million people suffered from permanent NIHL worldwide, which may position noise-induced hearing impairment as the most prevalent irreversible occupational hazard (Smith, A., 1998; Technical Learning College, 2005; World Health Organization, 1999). Globally there is weak enforcement and poor implementation of NIHL prevention programs, as well as a lack of employee awareness and education for hazardous noise (WHO, 1997). The exception to this is North America, Europe, and Japan, where occupational noise regulations have been enforced and implemented, but environmental noise pollution is now a growing concern (WHO, 1997). Due to the global impact of hearing loss, NIOSH, along with the occupational safety and health community, has declared hearing loss in the 21 priority areas for research in the next century (NIOSH, 2008).

2.1 Characteristics of Sound

2.1.1 Physics

2.1.1.1 Properties of Sound

From an auditory perspective, sound and noise consist of similar characteristics (WHO, 1999, chapter 2). Sound (or noise) is the result of pressure fluctuations in a medium (air, water, or solid) caused by a vibrating surface or turbulent fluid flow (ACGIH, 2006; Cowan, J., 1994; Hansen, C., 2001; Johnson, D.L., Papadopoulos, P., Takala, J., Watfa, N., 2001; Knight, R.D. and Baguley, D.M., 2007; WHO, 1980). When sound waves propagate in air, the fluctuations in pressure above and below the ambient atmospheric pressure result in longitudinal waves parallel to the source due to the compression of air molecules (Hansen, C., 2001; Technical Learning College, 2006). The difference between the highest and lowest air pressure determines the amplitude of a sound wave, which is then perceived by the listener as loudness (Sataloff, R. and Sataloff, J, 2006, p. 6; Schuder, M., 2006). Sound waves can be continuous or intermittent as they travel from the source to the site of detection with the air particles merely oscillating locally (ACGIH, 2006; Hansen, C., 20001). Frequency and wavelength are related through the speed of sound and are used to describe the direction and duration sound waves travel (Cowan, J., 1994; Hansen, C., 2001; Hirschorn, M., 1989; NIOSH, 1998).

The frequency of sound, (measured in hertz, Hz), is the number of vibrations, (or cycles), that occur in 1 second, and the perceived pitch of a sound by the listener increases with an increase in frequency (Cowan, J., 1994; Hirschorn, M., 1989; Knight, R.D. and Baguley, D.M., 2007; Sataloff R. and Sataloff J., 2006, p.6; U.S. DOL, 2008). As sound travels through a medium the distance between sound wave peaks in one cycle is its wavelength (Cowan, J., 1994; Hirschorn, M., 1989; Knight, R.D. and Baguley, D.M., 2007; U.S. DOL, 2008). The length of the wavelength is dependent upon the frequency of the sound. Lower frequencies have longer wavelengths and are less readily absorbed, whereas high frequencies have short wavelengths and can be attenuated more easily (Knight, R.D. and Baguley, D.M., 2007; Sataloff R. and Sataloff J., 2006, p.6).

The speed of a sound wave is the measure of how fast sound travels through air. The speed of sound varies directly with the density and inversely with the compressibility of the medium, i.e. speed increases as the density of the medium it travels through increases (U.S. DOL, 2008). The speed of propagation of sound in air at standard temperature and pressure, (20°C and 29.92" Hg, respectively), is approximately 344 meters per second (Cowan, J., 1994; Hirschorn, M., 1989; Knight, R.D. and Baguley, D.M, 2007; Sataloff R. and Sataloff, J., 2006, p.6; U.S. DOL, 2008,).

The properties of sound previously discussed refer to pure tones, or tones having only one frequency, and are very rarely found in environmental and industrial settings. Instead, sound that is experienced by the human ear is typically comprised of many frequencies at varying levels therefore; noise is often separated into its various frequency components in order to properly represent the total noise of a source in a room (Cowan, J., 1994; Hirschorn, M., 1989; Knight, R.D. and Baguley, D.M., 2007; NIOSH, 1998; Sataloff R., and Sataloff, J., 2006, p.7). The amount of noise experienced by the human ear is also dependent on the sound paths within a room that enable its propagation.

2.1.1.2 Propagation of Sound

Sound produced from certain processes and equipment is capable of direct sound and reverberant sound, figure 2.1. Direct sound is propagated by the source where it is most predominate and does not experience reflection from other surfaces in the room. Direct sound travels in a straight line directly to the receiver decreasing in pressure the further it travels away from the source (Hansen, C., 2001; Hirschorn, M., 1989; Ostergaard, P., 2003). Reverberant sound is the acoustical energy from sound waves that is reflected, or bounced off a barrier (Hansen, C., 2001; Hirschorn, M., 1989; Knight, R.D., Baguley, D.M., 2007; Ostergaard, P., 2003). When sound has been reflected, these sound waves can affect other sound waves that have been produced after it. When two waves traveling in different directions cross each other, they are said to be in phase and add together to produce a larger amplitude. This is known as constructive interference. On the other hand, sound waves can cancel each other when out of phase to produce no sound, known as destructive interference (Knight, R.D. and Baguley, D.M., 2007; Sataloff R and Sataloff J, 2006, p.6).

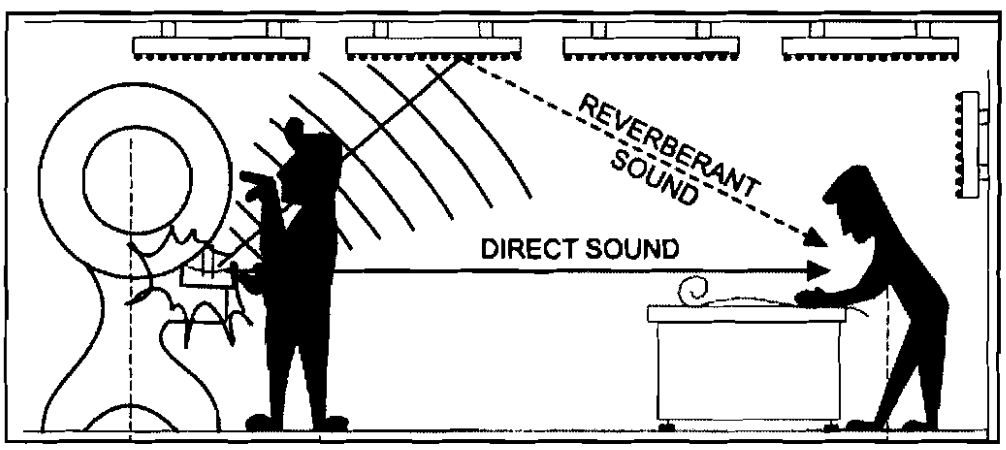

Figure 2.1. Diagram of direct and reverberant sound fields. From *Noise Control Reference Handbook* (p. C-3), by Hirschorn, M., 1989, New York: Industrial Acoustics Company. Copyright 1982 by Industrial Acoustics Company. Reprinted with permission.

2.1.1.3 Ultrasonics

The theoretical physical properties described for audible sound can also be applied to ultrasonic sound in air. However, the high frequency of ultrasound is often above the range of human hearing (Acton, W.I., 1974; Berger, E. H., 1996; Cowan, J., 1994; Howard, C. Q. et al., 2005; NIOSH, 1998; Pawlaczyk-Luszczynska, M. et al., 2007; Wiernicki, C. & Karoly, W. J., 1985).

Ultrasound waves are either continuous or pulsed (depending on the source) and have shorter wavelengths compared to audible sound (Acton, W.I., 1983; Cowan, J., 1994; U.S. DOL, 2008; Wiernicki, C. & Karoly, W.J., 1985). At 20,000 Hz the wavelength of ultrasound is approximately 17 mm and decreases in length as frequency increases (Acton, W.I., 1983; Sataloff, R. and Sataloff, J., 2006, p.6). Ultrasound is very directional and is readily reflected, absorbed, and transmitted (Acton, W.I., 1983; Cowan, J., 1994; Herman, B. & Powell, D., 1981; Leighton, T., 2007; U.S. DOL, 2008; Wiernicki, C. & Karoly, W.J., 1985). Absorption of ultrasound in air rapidly reduces the amplitude of the field as it travels away from the source (Acton, W.I., 1983; Leighton, T., 2007; Wiernicki, C. & Karoly, W.J., 1985).

2.1.2 Perception

2.1.2.1 Frequency Sensitivity

The audio frequency range for young adults with normal hearing is between 20 Hz and 20,000 Hz (Alberti, P., 2001; Cowan, J., 1994; Howard, C. Q. et al., 2005; Knight, R.D. and Baguley, D.M., 2007; Leighton, T., 2007; NIOSH, 1998; U.S. DOL, 2008; WHO, 2001). The intensity of sound needed for perception varies with frequency. The sound pressure levels perceived by unimpaired people begin at 70 dB at 20 Hz and passes through 0 dB at 1,000 Hz, with a minimum of -8 dB at 3 kHz (U.S. DOL, 2008). Many people lose sensitivity for the higher-frequency sounds as they grow older, beginning around 40 years of age (U.S. DOL, 2008). Reduction in the sensitivity to sound can be caused by disease, trauma, and hereditary syndrome as well as noise exposure (Health Information Publications, 2004).

2.1.2.2 Communication Frequency

Below 20 Hz humans perceive individual sound pulses rather than recognizable tones (WHO, Chapter 2, 1999). Above 20 Hz, specifically at frequencies between 200 Hz and 8,000

Hz, the human ear comprehends speech (ACGIH, 2006; Baker, D., 1993; Cowan, J., 1994; Knight, R.D. and Baguley, D.M., 2007; NIOSH, 1991; Robinson, G.S. and Casali, J.G., 2003; Suter, A., 1991; U.S. DOL, 2008; WHO, Chapter 3, 1999). Speech pronunciation of vowel sounds is distinguished at the lower end of these frequencies (200 Hz) and consonants at the higher end (8 kHz) (Cowan, J., 1994; Knight, R.D. and Baguley, D.M., 2007; Suter, A., 2001; U.S. DOL, 2008; WHO, Chapter 3, 1999).

2.1.3 Physiology of Hearing

The phenomena of comprehending fluctuations in air pressure could not occur without a key auditory sense, the human ear. The outer, middle and inner ear function together to allow for the perception of sound in day-to-day activities which are important for human well-being (WHO, 1999). The following diagram (figure 2.2) depicts the components of the human ear which will be described in more detail.

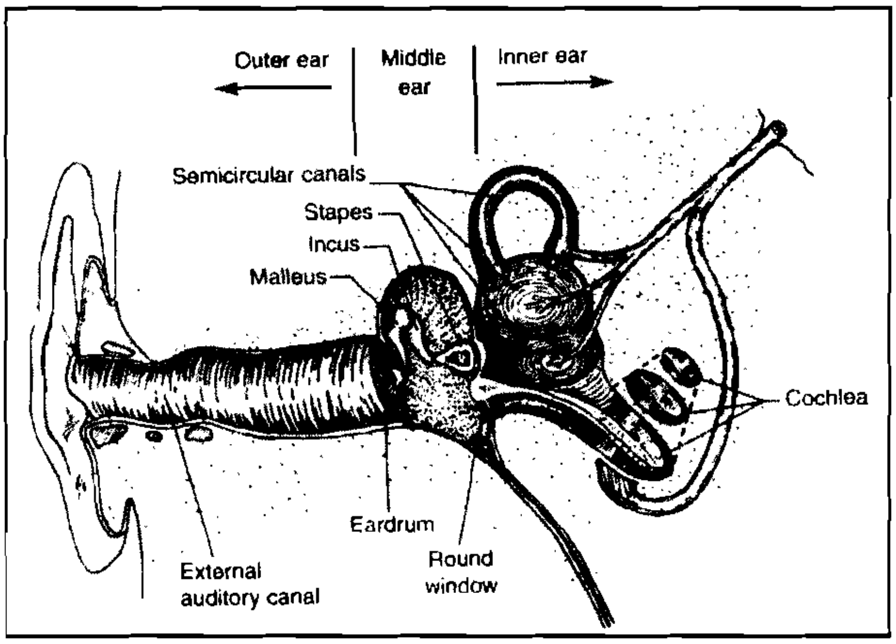

Figure 2.2. Cross-sectional view of the human ear. From *The Noise Manual* (p. 102), by Ward, D. et al., 2003, Indiana: American Industrial Hygiene Association. Copyright 2008 by American Industrial Hygiene Association. Reprinted with permission.

2.1.3.1 Outer Ear

The outer ear is made up of the pinna, or simply the ear, and the external auditory canal, or the earcanal. The outer ear collects sound waves and channels it into the ear canal where it is modified before reaching the ear drum (Alberti, P., 2001; U.S. DOL, 2008; Ward, D., Royster, L., Royster, J., 2003, p.102). The earcanal amplifies sounds between 3,000 Hz and 4,000 Hz, which increases the sensitivity and susceptibility to damage of the ear at these frequencies (Alberti, P., 2001; Ward, D. et al., 2003, p.103).

2.1.3.2 Middle Ear

At the end of the ear canal is the tympanic membrane, or eardrum, which is the beginning portion of the middle ear. Sounds are transferred from the eardrum to the inner ear by the vibration of three bones, the malleus (hammer), incus (anvil), and stapes (stirrup) (Alberti, P., 2001; U.S. DOL, 2008; Ward, D. et al., 2003, p.103). Attached to the malleus and stapes are muscle – the tensor tympani and stapedius, respectively. These muscles support the bones of the middle ear by maintaining their position and also aid in protecting the inner ear (U.S. DOL, 2008; Ward, D. et al., 2003, p.104). These muscles will contract upon the presence of vocalization or loud sounds which reduces the transfer of low-frequency energy to the inner ear (U.S. DOL, 2008; Ward, D. et al., 2003, p.105). Although these muscles are capable of full contraction in a tenth of a second, this does not allocate enough time to protect against impulse or long-term steady state exposures to noise (U.S. DOL, 2008; Ward, D. et al., 2003, p.105). Also a part of the middle ear is the Eustachian tube. This tube is extended from the beginning of the middle ear to the nasal air passages and equalizes air pressure on either side of the eardrum (Alberti, P., 2001; U.S. DOL, 2008; Ward, D. et al., 2003, p.105). Together, the outer and middle parts of the ear amplify sound on its passage from the exterior to the inner ear by 10 dB to 30 dB

(Alberti, P., 2001; Technical Learning College, 2005; U.S. DOL, 2008; Ward, D. et al., 2003, p.103).

2.1.3.3 Inner Ear

The function of the inner ear is to convert the sound waves transmitted from the outer and middle ear into neural impulses recognized by the brain (Ward, D. et al., 2003 p.105). This occurs in the cochlea, which is a coiled tube resembling a snail with the Reissner's and basilar membranes extending the length of the tube (Ward, D. et al., 2003, p.105). These neural impulses are initiated by movement of the basal membrane (Ward, D. et al., 2003, p105). Resting along the basal membrane are hair cells, approximately 4,000 inner hair cells and three rows of 12,000 hair cells throughout the cochlea (U.S. DOL, 2008; Ward, D. et al., 2003, p.105). When the basal membrane shifts up or down, the hair cells bend activating an electrochemical response that travels to the brain and interprets the signal (U.S. DOL, 2008; Ward, D. et al., 2003, p.105).

2.1.4 Perception of the Ultrasonic Sound

Ultrasonic sound is comprised of high frequencies, above 20 kHz, that are inaudible to the human ear (NIOSH, 1998). Due to the ear's anatomy and its sensitivity to high frequency sounds, the human ear is quite vulnerable to the ultrasonic sound range (ACGIH, 2006; Henderson, D. and Hamernik, R.P., 1986; U.S. DOL, 2008). The high-intensity sound waves of ultrasound can be transmitted to the ear with a force that the ear cannot tolerate (Baker, D., 1993). This results in the depletion of sensory cells in the ear for the highest audible frequencies (Grzesik, J. and Pluta, E., 1986).

2.2 Health Effects of Occupational Noise

Occupational exposure to noise levels in excess of proposed guidelines is a global concern (Concha-Barrientos, M., 2004; Goines, L. and Hagler, L., 2007; Lawton, B.W., 2001;

WHO, Chapter 3, 1999). Despite this concern, the effects of noise are often underestimated because the damage of excessive noise exposure has a gradual affect on the human auditory mechanism rather than a rapid sensory affect such as a burn (Danielson, R. W., 2008). Furthermore, the decline in state and local noise control programs and the lack of workforce awareness suggest that the health effects caused by this type of hazard are taken lightly (Shapiro, S., 1991). The consequence of this type of hazard is dependent on the amplitude, frequency, pathway, duration, and the individual's receptiveness to the noise exposure (Johnson, D.L. et al., 2001; Lawton, B.W., 2001; NIOSH, 1998). Another factor to consider when assessing the health effects of noise is the equal-energy rule.

The concept of the equal-energy rule is that the total sound energy experienced by the human ear determines the risk for hearing loss (Sulkowski, W., 2007). Thus, the hazard of one 4.8 minute 90 dBA burst of noise would pose the same risk of hearing loss as 10- 90 dBA bursts lasting only 0.48 minutes (Ward, D. et al., 2003, p.137). ACGIH purports this rule as being the most practical and reasonable method for measuring continuous or intermittent noise with impulse noise between 80 dBA and 140 dBA (2008). The equal-energy rule also determines the exchange rate. The doubling or halving of the allowable duration to a noise exposure based on a 3 dB exchange rate is consistent with the equal-energy (ACGIH, 2006; Ward, D. et al., 2003, p.138). The 3-dB rule is more strongly supported then the 5-dB rule used by OSHA (ACGIH, 2006; Ward, D. et al., 2003, p. 138). Studies indicate that the 3-dB rule is more conservative than the 5 dB rule. The 5 dB exchange rate underestimates the average sound pressure level during rapidly varying sound and therefore does not protect the human hearing system from high-level, short duration noise exposures (ACGIH, 2006; NIOSH, 1998; Ward, D. et al, 2003, p140). Part of the rationale for OSHA's use of the 5 dB exchange rate is because intermittent noise exposure allows for short-term recovery of the ear during the quiet periods of the exposure which aids in the reduction of any permanent damage to ear (Ward, D. et al., 2003, p.138).

Hazardous noise can be in the form of excessive audible noise, ultrasound, and impulse noise. Each type of noise can cause direct and indirect health effects including: hearing impairment, interference with verbal communication, create physical and psychological stress, sleep disturbances, reduce productivity, create negative social behavior and annoyance reactions, and contribute to accidents and injuries by making it difficult to hear warning signals (ACGIH, 2006; Babisch, W., 2005; Cowan, J., 1994; Goines, L. and Hagler, L., 2007; Hearing Foundation of Canada, 2007; NIOSH, 2008; Pawlaczyk-Luszczynska, M. et al., 2007; Sulkowski, W., 2007; U.S. DOL, 2008; WHO, 1999; WHO, 2001; WHO, 2004). The ACGIH has published guidelines for occupational exposure to audible noise, ultrasound, and impulse noise which they believe will minimize the adverse effects on the human body (Appendix A). OSHA also has regulatory permissible exposure limits for audible noise and utilizes the ACGIH guidelines for ultrasound noise exposure (Appendix A) (U.S. DOL, 2008).

2.2.1 Noise Induced Hearing Loss

Noise-induced hearing loss (NIHL) has been a recognized hazard in the occupational setting for years (ACGIH, 2006; Sulkowski, W., 2007). NIHL occurs from repeated exposure to excessive noise levels that damage the sensory cells of the cochlea in the inner ear, and can be temporary or permanent (Babisch, W., 2005; Goines, L. and Hagler, L., 2007; Lawton, B.W., 2001; NIOSH, 1998; Suter, A., 1991; WHO, 2004). Research has shown that sound levels below 75 dB do not cause NIHL and that sound 85 dB or greater can cause hearing loss (Babisch, W., 2005; Goines, L. and Hagler, L., 2007; Toronto Public Health, 2000; WHO, 1999). Auditory effects that result from NIHL are loudness recruitment (an abnormal perception of loudness), paracusis (distortion of sounds), and tinnitus (ringing in the ears) (Goines, L. and Hagler, L., 2007; WHO, 1999). Initially, exposure to high noise levels can cause auditory fatigue. The fatigue is noticeable in the short term as an increase in the threshold of hearing, predominately in the 1,000 Hz to 4,000 Hz range (Baker, D., 1993; NIOSH, 1998; U.S. DOL, 2008; WHO, 2004). This temporary loss of hearing is known as noise-induced temporary threshold shift (NITTS). Normal hearing returns after several hours or days assuming the exposure is not continued (U.S. DOL, 2008; WHO, 2004).

Progressive threshold shifts from 500, 1,000, 2000, and 3,000 Hz is the irreversible result of NIHL, and increases in severity with continued exposure (ACGIH, 2006; WHO, 2004). The risk for noise-induced permanent threshold shift (NIPTS) is determined by the intensity, frequency, duration and distribution of the noise, and the susceptibility of the worker (ACGIH, 2006; NIOSH, 2008; Sulkowski, W., 2007; Technical Learning College, 2005). NIPTS is defined as an increase in the average hearing threshold of 25 dB for the 3,000 to 6,000 Hz range; generally the greatest decrease in sensitivity occurs at 4,000 Hz (Baker, D., 1993; Lawton, B.W., 2001; NIOSH, 1998; U.S. DOL, 2008). Occupationally caused hearing loss is generally bilateral (Suter, A., 1991; Ward, D. et al., 2003, p. 128; WHO, 1980). NITTS and NIPTS can differ amongst individuals by as much as 30 dB – 50 dB (Sulkowski, W., 2007; Suter, A., 1991; WHO, 1999).

2.2.2 Speech Interference

As stated by ACGIH (2006, p. 3), "the ability to hear and understand everyday speech under normal conditions is regarded as the most important function of the hearing mechanism." NIHL make it difficult to differentiate the frequencies of speech perception, 2,000 – 4,000 Hz, (Baker, D., 1993; NIOSH, 1998). When speech is not comprehendible there is miscommunication amongst coworkers, and additional strain on the vocal system due to employees having to raise their voice to communicate (WHO, 1999). Furthermore, employees may become irritated or annoyed and have a lack in concentration, safety, and productivity due to excessive noise levels (Goines, L. and Hagler, L., 2007; WHO, 1999). The reverberation characteristics in a room also effect speech communication amongst workers. Longer reverberation times, combined with high background interfering noise, make speech perception more difficult (WHO, Chapter 3, 1999). The higher the noise level, the greater the masking effect noise has on the ear, resulting in additional adverse consequences to receiver (Suter, A., 1991; WHO, 1999).

2.2.3 Physical Stress

Occupational exposures to noise cause adverse health effects to the human body by acting as a stressor (Goines, L. and Hagler, L., 2007). Workers exposed to high levels of industrial noise for 5 – 30 years have an increased heart rate, blood pressure, blood viscosity, and are more prone to cardiovascular diseases (Goines, L. and Hagler, L., 2007; Johnson, D.L. et al., 2001; U.S. DOL, 2008; WHO, Chapter 3, 1999).

2.2.4 Psychological Stress

Noise exposure has been linked to accelerate the development of mental illness and intensify the body's response to the disease once onset (Goines, L. and Hagler, L., 2007; WHO, Chapter 3, 1999). Noise exposure may also cause anxiety, anger, stress, and nervousness (Goines, L. and Hagler, L., 2007; Johnson, D.L. et al., 2001; Ward, D. et al., 2003, p. 143; WHO, Chapter 3, 1999).

2.2.5 Impaired Task Performance and Accident Contribution

Some types of noise may adversely affect a person's cognitive task performance while other types of noise improve performance (Goines, L. and Hagler, L., 2007; Suter, A., 1991; WHO, Chapter 3, 1999). Noise disturbances can interfere with complex tasks, but generally do not affect repetitive tasks (Johnson, D.L. et al., 2001; Suter, A., 1991; WHO, Chapter 3, 1999). Disturbances from noise can increase error rates, decrease motivation, and extend task completion times (Johnson, D.L. et al., 2001; Smith, A., 1990; WHO, Chapter 3, 1999). Noise in an occupational setting coupled with employees who experience NIHL may not only result in poor performance, but pose a grave safety hazard (Suter, A., 1991). There are few studies linking unsafe behavior with noise. In the event of an emergency, excessive noise may prevent workers from hearing warning signals or shouts of a coworker which may lead to injury (WHO, 1980). Furthermore, worker distraction due to noise may increase the frequency of accidents (Smith, A., 1990).

2.2.6 Ultrasonic Sound

Exposure to industrial airborne ultrasound is capable of producing subjective health effects as well as temporary threshold shifts from short exposure levels greater than 150 dB (ACGIH, 2001; Acton, W. I., 1983; Bly, S. and Deirdre, M., 1991; Howard, C. Q. et al., 2004; Wiernicki, C. et al., 1985; WHO, 1982). However, the amount of NITTS experienced from ultrasound is due to specific frequencies and sound-pressure levels (Bly, S. and Deirdre, M., 1991; Howard, C. Q. et al., 2005; WHO, 1982). Concern for the exposure effects associated with ultrasonic sound began in the late 1940's with employees working around jet engine aircrafts complaining of "ultrasonic sickness" (Acton, W. I., 1983; Berger, E. H., 1996; Bly, S. and Deirdre, M., 1991).

The health effects associated with ultrasonic sickness include headaches, fatigue, nausea, tinnitus, and slight dizziness (Acton, W.I., 1983; Bly, S. and Deirdre, M., 1991; Damongeot, A. and Andre, G., 1988; Herman, Bruce & Powell, David, 1981; WHO, 1982). The reported symptoms of ultrasonic sickness generally disappear shortly after the exposure (Acton, W.I., 1983). The symptoms of ultrasonic sickness are caused by a reaction of the central nervous system to the excessive levels of high frequency audible noise emitted as subharmonics from the source (Acton, W. I., 1983; Bly, S. and Deirdre, M., 1991; Crabtree, R. B. et al., 2000; WHO, 1982). Ultrasonic noise is not damaging to the human auditory system when less than 120 dB, and it has no effect on general health unless there is direct body contact with an ultrasonic source (Bly, S. and Deirdre, M., 1991; Hanson, C., 2001; McLaughlin, D., 2000). Airborne ultrasound sound-pressure levels greater than 150 dB may however cause harmful effects to the human body (Acton, W.I., 1983; Bly, S. and Deirdre, M., 1991).

The majority of the effects that excessive airborne ultrasound has on the body is an outcome of sound absorption through skin and tissues via direct body contact. When airborne ultrasound enters the ear, it causes the hair cells of the inner ear to vibrate and produce heat at the site (WHO, 1982). The absorption of this type of noise through human skin produces slight body heating (Acton, W.I., 1983; Bly, S. and Deirdre, M., 1991; Parrack, H., 1966; WHO, 1982). The sound-pressure levels required to produce these types of adverse health effects have not been encountered in the industrial setting or in commercial applications (Bly, S. and Deirdre, M., 1991; Herman, B. and Powell, D., 1981; Parrack, H., 1966). The upper sonic range of hearing and subharmonics emitted from ultrasonic sources appear to be more hazardous to human health then ultrasonic noise alone (Bly, S. and Deirdre, M., 1991).

ACGIH guidelines for ultrasound include ceiling values as well as 8 hour TWA (Appendix A). The limits set by ACGIH are much greater than proposed limits amongst other organizations such as the Occupational Safety and Health Branch in Canada, and the International Radiation Protection Agency (IRPA), table 2.1. The limits set by Health Canada were based on conclusions from the IRPA, which also provide recommendations for the World Health Organization (Bly, S. and Deirdre, M., 1991; Howard, C. Q. et al., 2005). The proposed guidelines by IRPA and Health Canada are more conservative and are often used to prevent the occurrence of subjective effects of ultrasound (Howard, C. Q. et al., 2005).

Table 2.1. Comparison of ultrasound ceiling values listed in dBA (Bly, S. and Deirdre, M., 1991).

1/3 Octave Frequency Bands	10	12.5	16	20	25	31.5	40	50	63	80	100
ACGIH	105	105	105	105	110	115	115	115	115	115	115
IRPA	-	-	-	75	110	110	110	110	-	-	-
Health Canada	-	-	75	75	110	110	110	110	-	-	-

2.3 Sources of Ultrasonics

2.3.1 Uses of Ultrasonics

Powerful industrial ultrasonic equipment and commercial products may be able to produce relatively high ultrasound intensities for short distances around equipment (Bly, S. and Deirdre, M., 1991; Wiernicki, C. et al., 1985). The hazard associated with industrial ultrasonic equipment is the possible contact exposure to the ultrasonic sound wave and the generation of high sound-pressure levels (Bly, S. and Deirdre, M., 1991). Ultrasonic sources can be either low power or high power (Wiernicki, C. and Karoly, W.J., 1985). Lower power applications generate noise in the megahertz (MHz) range and are used more in the health care setting (for examination) rather than the industrial setting (for altering material).

High power outputs are used for low frequency vibration-induced mechanisms to physically change the material (Acton, W. I., 1974; Howard, C. Q. et al., 2005; Pawlaczyk-Luszczynska, M. et al., 2007; WHO, 1982; Wiernicki, C. and Karoly, W.J., 1985). Industrial applications of high power ultrasound include: washers, plastic and metal welders, drills, soldering and braising tools, and galvanizing tools (Acton, W. I., 1974; Bly, S. and Deirdre, M., 1991; Herman, B. and Powell, D., 1981; Howard, C. Q. et al., 2005; Pawlaczyk-Luszczynska, M. et al., 2007; WHO, 1982). These applications generally operate at 20 kHz, but can range from 20 kHz to 300 kHz (Bly, S. and Deirdre, M., 1991; WHO, 1982). Commercial devices of ultrasound include: humidifiers, burglar alarms, garage door openers, remote controls, and rodent and pest repellers (Bly, S. and Deirdre, M., 1991; Herman, B. and Powell, D., 1981; Leighton, T., 2007; WHO, 1982).

Many of these industrial and commercial devices that use ultrasound incidentally generate and propagate high sound-pressure levels in the air in the sonic and ultrasonic range (Bly, S. and Deirdre, M., 1991). Much of the airborne ultrasound generated from these commercial devices is rapidly absorbed in air (Leighton, T., 2007; WHO, 1982).

2.3.2 Ultrasonic Welding

Ultrasonic welding of plastics is a solid-state joining process that uses a high-frequency vibration to heat the plastic components and melt them together (Doumandis, C. and Gao, Y., 2004; Rotheiser, J., 2004). A typical ultrasonic welder consists of a transducer, the booster, and the sonotrode (or horn). The transducer converts electrical energy from an outside source power supply into high frequency mechanical vibrations (Rotheiser, J., 2004). The booster adjusts the amplitude of the vibrations desired at the joint interface (Rotheiser, J., 2004). The booster is located between the transducer and the horn. The sonotrode then transmits the vibratory energy and the force from the booster to the parts to be welded through direct contact (Bly, S. and Deirdre, M., 1991; Rotheiser, J., 2004). The horn must properly fit the piece being welded; otherwise the weld will not be even (Rotheiser, J., 2004). The energy required to produce the weld is dependent on the hardness and thickness of the materials being joined (Gibson, S., 1997). The hazards associated with ultrasonic welding to the user are direct contact with the ultrasonic wave and exposure to high sound-pressure levels (Bly, S. and Deirdre, M., 1991).

2.4 Measurement

2.4.1 Sound Measurement

The most commonly used instruments in measuring noise exposure are sound level meters (SLM) and noise dosimeters (NIOSH, 1998). SMLs and noise dosimeters have criteria that the operator can choose in order to collect the appropriate data from the instrument. These settings include the option for frequency weighting, response, threshold, exchange rate, and criterion level. The frequency weightings provide a composite SPL that can be set to mimic the human ear (Earshen, J., 2003; WHO, 1999).

The types of weighting filters consist of A, B, C, and Z (Michael, P. and Michael, K., 2006). The A-weighting is the most commonly used frequency weighting filter because it closely approximates the loudness perception characteristics of human hearing for pure tones at 40 phons (Earshen, J., 2003; WHO, 1999). The A-weighting scale provides a realistic estimation of the risk of hearing loss (Earshen, J., 2003; WHO, 1999). The B-weighting scale has few applications (Earshen, J., 2003). The C-weighting is typically used in measuring sound that is blast-type or impulsive in nature. The C-weighting includes much of the low frequency sound energy, whereas the A weighting detects mid to high frequencies (Earshen, J., 2003). The Z-weighting, or flat-weighting, adds all frequencies equally (Earshen, J., 2003). Figure 2.3 represents the response detected for each weighting scale at various frequencies.

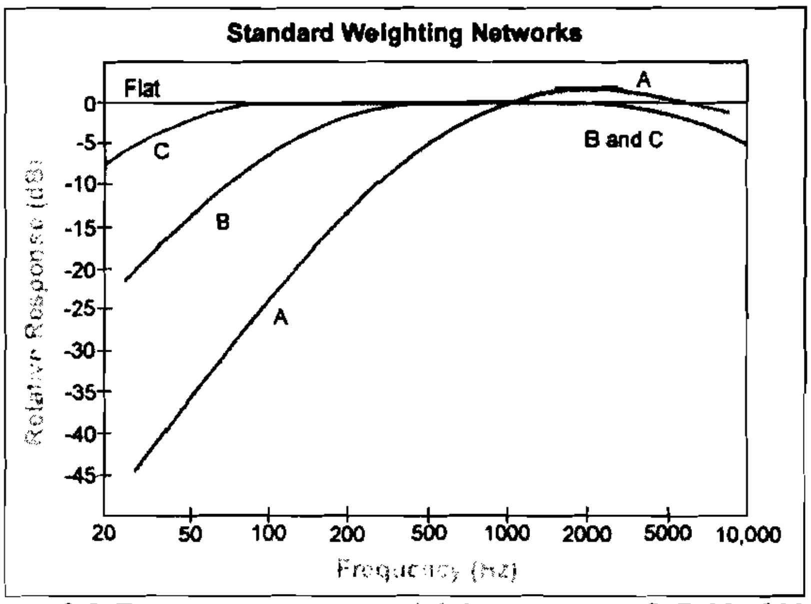

Figure 2.3. Frequency response weighting curves (U.S. DOL, 2008).

The response setting of the instrument establishes how fast the meter can reach a steady-state value and record changes in sound level. The response of an instrument can be adjusted to slow or fast. A slow response setting has a one-second time constant and achieves a steady-state SPL value after 2 seconds (NIOSH, 1998; Quest Technologies Inc., 2005). A fast response setting has a time constant of 125 milliseconds and achieves a steady-state SPL value after 500 milliseconds (NIOSH, 1998; Quest Technologies Inc., 2005). Typically, the slow response will be used when determining the average value of an observed sound and the fast response when estimation in the variability of sound is needed (Earshen, J., 2003). The response mandated by OSHA and recommended by ACGIH and NIOSH is slow. This is because the instrument will tend to fluctuate rapidly in the fast response, resulting in a higher recorded sound-pressure level (NIOSH, 1998).

The threshold is the 'cut-off' limit of the instrument. All sound below the threshold sound-pressure level is not included in values recorded by the instrument. The threshold value affects the Lavg, TWA, and dose measurements. Both OSHA and ACGIH recommend threshold values of 80 dB (ACGIH, 2006; Quest Technologies Inc., 2005; U.S. DOL, 2008). The maximum allowable sound-pressure level exposure for the criterion time of 8 hours is the criterion level. The criterion level for the OSHA regulation is 90 dBA and for the ACGIH TLV is 85 dBA (ACGIH, 2006; Quest Technologies Inc., 2005; U.S. DOL, 2008I).

The exchange rate, also known as the doubling rate, is used to determine the duration of exposure for increases or decreases in sound-pressure level (Earshen, J., 2003; Quest Technologies Inc., 2005). The ACGIH recommended exchange rate is 3 dB, the OSHA regulation exchange rate is 5 dB. OSHA uses the 5 dB exchange rate because it represents the response characteristics of the human ear (Quest Technologies Inc., 2005).

2.4.2 Meters

2.4.2.1 Sound Level Meters

A sound level meter is a basic instrument for monitoring employee noise exposure (ANSI, 1983; U.S. DOL, 2008). A sound level meter consists of a condenser microphone and a preamplifier to detect pressure fluctuations in the air (System 824, 2006). The purpose of a sound level meter is to spot-check noise dosimeter performance, determine an employee's noise dose when a noise dosimeter is unavailable, identify and evaluate individual noise sources, aid in determining the need for engineering controls, and evaluate the need for hearing protection (McLaughlin, D., 1996; U.S. DOL, 2008). The ANSI standard S1.4-1983 outlines the requirements for OSHA evaluations (Earshen, J., 2003; McLaughlin, D., 1996; U.S. DOL, 2008). The ANSI standard identifies four types of SLMs, type 0- for use in a laboratory, type 1- for precise field work, type 2 - for general field work, and type S - for special purposes (ANSI, 1983; Earshen, J., 2003; Malchaire, J., 2006). The minimum standard for OSHA evaluations is the Type 2 meter.

2.4.2.2 Real-Time Analyzer

Real-time analyzers simultaneously measure and record octave bands or one-third octave band frequencies. Real-time analysis of octave band or one-third-octave band frequencies is useful for the assessment of complex frequency spectra, such as ultrasonic noise (Acton, W. I., 1983; Michael, P. and Michael, K., 2006; Wiernicki, C. et al., 1985). Table 2.2 lists one and one-third octave-band frequencies.

Table 2.2. Comparison of one and one-third octave band frequencies in Hz (Chan, A., 2008).

1 Octave			1/3 Octave		
Lower Cutoff	Center	Upper Cutoff	Lower Cutoff	Center	Upper Cutoff
11	16	22	14.1	16	17.8
			17.8	20	22.4
			22.4	25	28.2
22	31.5	44	28.2	31.5	35.5
			35.5	40	44.7
			44.7	50	56.2
44	63	88	56.2	63	70.8
			70.8	80	89.1
			89.1	100	112
88	125	177	112	125	141
			141	160	178
			178	200	224
177	250	355	224	250	282
			282	315	355
			355	400	447
355	500	710	447	500	562
			562	630	708
			708	800	891
710	1,000	1,420	891	1,000	1,122
			1,122	1,250	1,413
			1,413	1,600	1,778
1,420	2,000	2,840	1,778	2,000	2,239
			2,239	2,500	2,818
			2,818	3,150	3,548
2,840	4,000	5,680	3,548	4,000	4,467
			4,467	5,000	5,632
			5,632	6,300	7,079
5,680	8,000	11,360	7,079	8,000	8,913
			8,913	10,000	11,220
			11,220	12,220	14,130
11,360	16,000	22,720	14,130	16,000	17,780
			17,780	20,000	22,390

2.4.2.3 Dosimeter

A noise dosimeter is essentially a SLM that is worn on the body (Earshen, J., 2003; Michael, P. and Michael, K., 2006). A noise dosimeter measures and records the sound-pressure levels in the 'hearing zone' using a microphone positioned on the wearer's shoulder (Earshen, J., 2003). A noise dosimeter can provide average sound-pressure levels for a workshift, total workshift dose, and second-to-second SPL values (Earshen, J., 2003; Michael, P. and Michael, K., 2006). Type 1 noise dosimeters may be used in field work that requires more precision and provide an accuracy of ±1 dBA (U.S. DOL, 2008). The Type 2 noise dosimeters have an accuracy of ±2 dBA (U.S. DOL, 2008). They are primarily for general use and are the minimum criteria that can be used for compliance purposes (Michael, P. and Michael, K., 2006; U.S. DOL, 2008). Noise dosimeters are the preferred method for measuring personal noise exposures (NIOSH, 1998).

2.4.3 Measuring Ultrasound

Ultrasound is defined as sound that is inaudible to the human ear (NIOSH, 1998; U.S. DOL, 2008). In order to detect airborne ultrasound, a Type 1 SLM with a frequency response of the microphone and preamplifier above 20 kHz should be used (Bly, S. and Deirdre, M., 1991; Herman, B. and Powell, D., 1981). The OSHA regulation does not specify between using an A-weighted scale or Z-weighted (unweighted) scale for this measurement. The A-weighted level at 20 kHz one-third octave band will be 10 dB below a Z-weighted scale (U.S. DOL, 2008). Therefore, if an A-weighted instrument is used to measure ultrasound and detects a 95 dB tone at 20 kHz, the instrument will read 85 dBA (U.S. DOL, 2008). SLMs or dosimeters may detect the ultrasonic subharmonics (Acton, W. I., 1983; Brown, G. G., 1967; Crabtree, R. B. et al., 2000; Grzesik, J. and Pluta, E., 1983; Howard, C. Q. et al., 2005; Leighton, T., 2007; McLaughlin, D., 2000; Pawlaczyk-Luszczynska, M. et al., 2007; U.S. DOL, 2008; Wiernicki, C. et al., 1985;). One-third-octave or narrower band analysis is required for the assessment of complex frequency spectra, (such as airborne ultrasound), and comparison with the published criteria (Acton, W. I., 1983; Wiernicki, C. et al., 1985).

Chapter III: Methodology

This study examined worker exposure to ultrasonic noise during the ultrasonic welding of plastic to plastic parts and metal to plastic parts. This type of weld is characterized by a sharp, high-pitched screech like sound. The exposures of three employees were measured each day during an initial evaluation. The latter study evaluated exposures of employees operating the number 10 Branson welding unit. Each study utilized Type 1 and Type 2 personal noise dosimeters and real-time analyzers for the detection of noise.

3.1Research Strategy

The objectives of this study were to:

- Determine the range of sound-pressure level exposures experienced by workers using ultrasonic equipment as measured by Type 1 and Type 2 noise dosimeters.
- Compare the sound-pressure level measurements from the Type 1 and Type 2 noise dosimeters to current OSHA regulations and ACGIH guidelines.
- Determine the type of instrument most effective for evaluating ultrasonic noise.
- Identify if the amount of ultrasonic sound is dependent on the type of components being welded.
- Discuss the applicability of using the proposed sampling method in other industrial settings exposed to ultrasound.

3.2 Facility

3.2.1Processes at Company XYZ

Company XYZ manufacturers various medical components comprised of plastic and metal. The production floor is open and has welders, presses, and other manufacturing equipment in close proximity without any sound barriers or separation. The products being manufactured at this facility change on a daily basis, which generates different types and levels of sound each day.

3.2.2 Ultrasonic Welding at Company XYZ

Company XYZ uses ultrasonic welders to bond parts, (plastic to plastic or metal to plastic), of medical devices together because of the quick application and quality of the weld. Company XYZ houses many types of ultrasonic welders on the production floor. Due to the lack of space on the production floor, these welders are not separated from any other production activities. Depending on the type of weld and component being welded, (size, shape, and material), the ultrasonic welders emit high frequency audible noise that can contribute to the overall sound level generated on the production floor.

3.3 Apparatus

The instruments used to detect noise exposures at Company XYZ were paired in order to determine their efficacy. Type 1 and Type 2 noise dosimeter were labeled correspondingly and identified as set A, B, or C (table 3.1). Real-time analyzers with 1/3 octave band filters were coupled with the dosimeters in set A and set B and provided a more detailed analysis of the ultrasonic noise. The initial research utilized all three sets of instruments to determine the overall noise exposure and evaluate the types of dosimeters over a 3 day period. The later study used set B instruments to determine noise exposure during the operation of a single ultrasonic welder, unit #10, over a 5 day period. The parameters for the instruments for the initial evaluation were set to ACGIH guidelines and for the later evaluation the instruments were set to OSHA parameters (Appendix B).

Table 3.1. Noise instrument sets used for evaluating employee exposure.

Set A	Set B	Set C
Quest RTA	Larson Davis RTA	DOS 1-10
DOS 1-8	DOS 1-9	DOS 2-010
DOS 2-35008	DOS 2-13	

3.3.1 Ultrasonic Welder

The initial evaluation of ultrasonic noise exposure did not consider the manufacturer of the welder that employees were operating, but rather the amount of noise exposure occurring during the welding process. The later study focused on noise exposure of the operation of a Branson 2000 d/aed ultrasonic assembly system, unit #10. The nominal operating frequency of the Branson 2000 d/aed welder is 20 kHz and can be operated manually, semi-automated, or fully automated (Branson Ultrasonics Corporation, 1999). Specifications of this unit are presented in Appendix L.

3.3.2 Noise Dosimeter

The Quest NoisePro DLX-1 dosimeters are Type 1 dosimeters that have an accuracy of ±1 dB. Quest NoisePro DLX dosimeters are Type 2 dosimeters that have an accuracy of ±2 dB. The NoisePro dosimeters have a maximum peak level of 143 dB and threshold level of 140 dB (Quest Technologies Inc., NoisePro Brochure, 2008). The Quest noise dosimeters were calibrated using a Quest Model QC-20 calibrator which emitted a constant sound-pressure level of 114.0 dB. Snap-in adapters for the coupler opening on the calibrator were used to insert the microphones for dosimeter calibration. Quest NoisePro DLX-1 noise dosimeters with Class 1 prepolarized condenser microphones, and Quest NoisePro DLX noise dosimeters with Class 2 integrated microphones were used to determine employee exposure to ultrasonic noise at 1 second intervals. Figures 3.1 thru 3.6 depict the frequency response for each class of microphone at different angles.

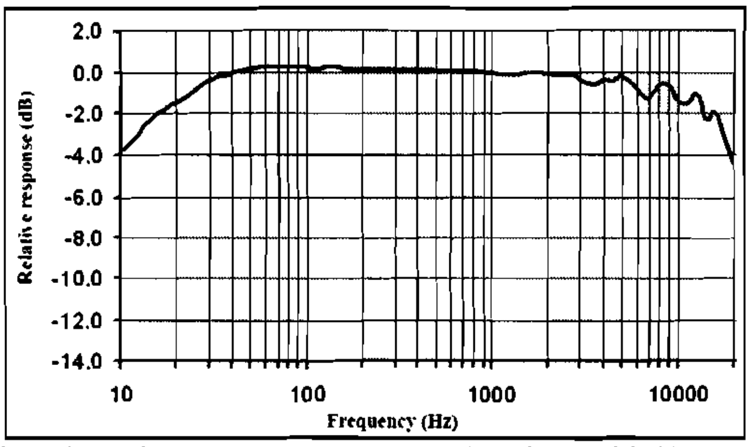

Figure 3.1. Class 1 microphone frequency response curve in a free field, 0°, no windscreen. From *NoisePro Owner's Manual* (p. 88). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

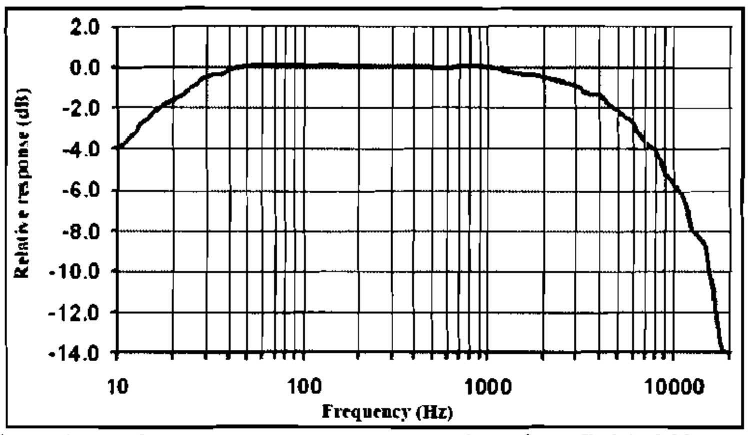

Figure 3.2. Class 1 microphone frequency response curve in a free field, 90°, no windscreen. From *NoisePro Owner's Manual* (p. 88). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

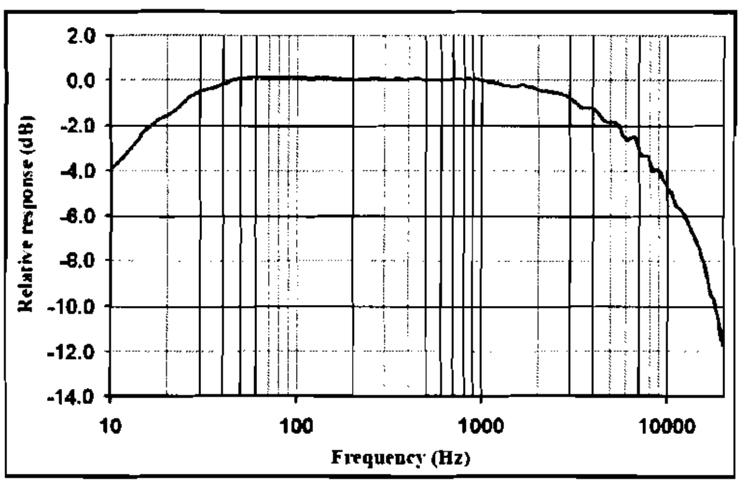

Figure 3.3. Class 1 microphone frequency response curve in random incidence, no windscreen. From *NoisePro Owner's Manual* (p. 89). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

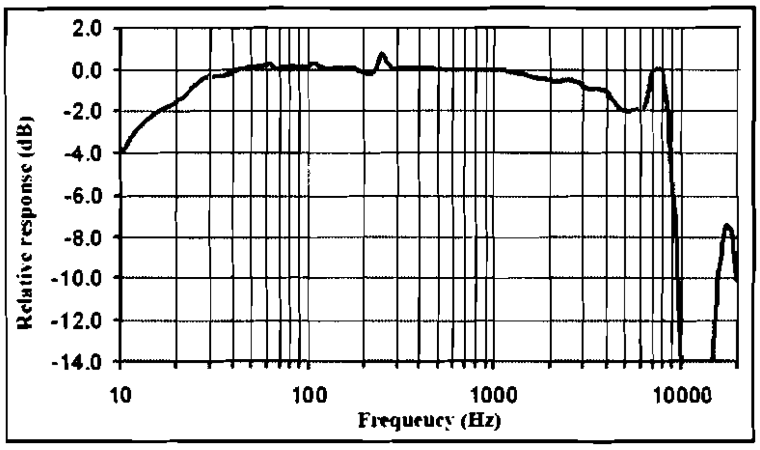

Figure 3.4. Class 2 microphone frequency response curve in a free field, 0°, no windscreen. From *NoisePro Owner's Manual* (p. 90). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

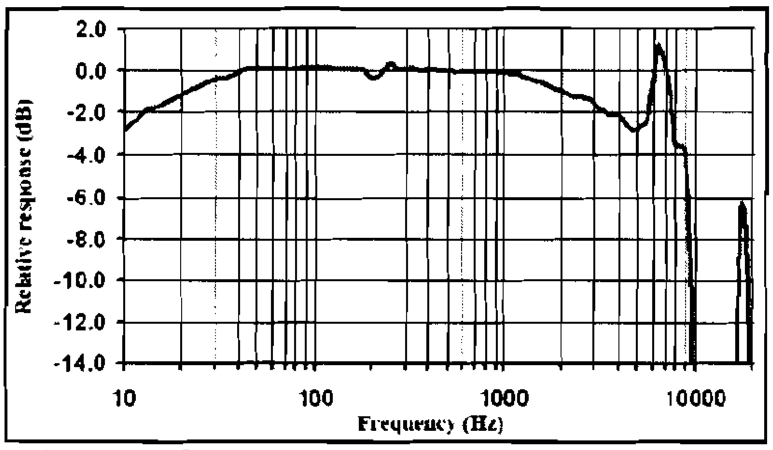

Figure 3.5. Class 2 microphone frequency response curve in a free field, 90°, no windscreen. From *NoisePro Owner's Manual* (p. 90). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

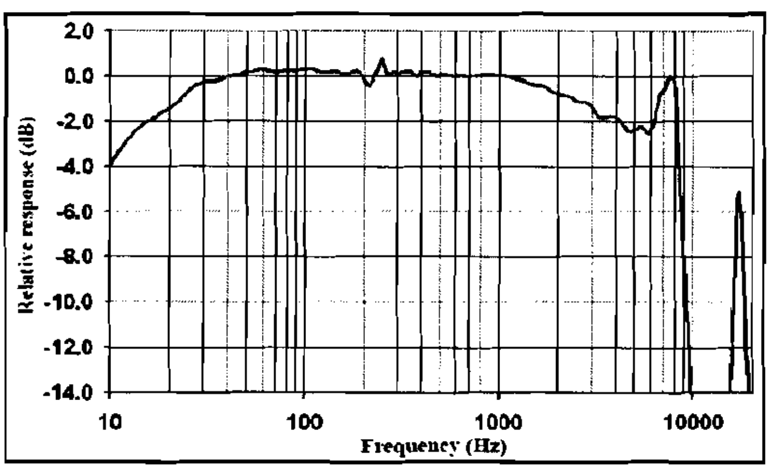

Figure 3.6. Class 2 microphone frequency response curve in random incidence, no windscreen. From *NoisePro Owner's Manual* (p. 91). Copyright 2005 by Quest Technologies, Inc. Reprinted with permission.

3.3.3 Real-Time Analyzer

Both Quest and Larson Davis real-time analyzers were used to evaluate ultrasonic noise exposure during the welding process at 1 second intervals. A Quest SE/DL SoundPro Real-Time Analyzer (RTA) was used in the initial study to evaluate ultrasonic noise exposure to the employees at 1/3 octave bands frequencies. Snap-in adapters for the coupler opening on the calibrator were used to insert the microphone for dosimeter calibration. The Quest RTA is a Type 1 sound level meter that operates between 3 Hz – 22.4 kHz with a threshold level of 140 dB and peak level of 143 dB (Quest Technologies Inc., Preliminary Technical Specifications, 2008). For the later data collection, the Larson Davis 824 Type 1 Sound Level Meter & Real-Time Analyzer was used. The Larson Davis Calibrator 150 was used with an adapter for microphone calibration. The calibrator operated at 1,000 Hz with an output sound-pressure level of 114.0 dB (Larson Davis, 2006). The Larson Davis 824 condenser microphone connected to the preamplifier and allowed for the detection of 1/3 octave band frequencies between 12.5 kHz and 20 kHz with a peak level of 160 dB (Larson Davis, 2006).

3.3.4 Software

To analyze the noise exposures recorded by the dosimeters and real-time analyzers, QuestSuite Professional II software, Larson Davis 824 Utility 3.12 software, Microsoft Office Excel 2007, and KaleidaGraph version 4.0 graphing and data analysis application were used.

3.4 Test Procedures

3.4.1 Calibration

Each sample day, prior to evaluating employee exposure to ultrasonic noise, Type 1 and Type 2 Quest NoisePro noise dosimeters and the Quest SE/DL RTA were pre-calibrated using the QC-20 calibrator to 114.0 dBA. The Larson Davis System 824 RTA was also pre-calibrated to 114.0 dBA using the Larson Davis Calibrator 150. After the employee workshift, post-calibration measurements were taken for all instruments using the same equipment for pre-calibration measurements (Appendix B).

3.4.2 Exposure Measurement

Employee noise exposure data to ultrasonic sound was obtained for 8 workdays. The employee who was operating the selected ultrasonic welders the day of sampling reported to the researcher prior to beginning their shift. The researcher assembled a vest for the employee to wear that contained microphones for each instrument which were placed strategically in the vicinity of the employee's hearing zone (figure 3.7). The Type 1 and Type 2 Quest NoisePro noise dosimeters were connected to the appropriate microphone on the vest adjacent to each other. The Quest SE/DL RTA or the Larson Davis System 824 RTA was then connected to the appropriate microphone on the vest dependent upon the pair of noise dosimeters used the day of sampling.

Figure 3.7. Vest with connected noise equipment in the hearing zone of the employee used to sample exposures.

After the employee was vested, they then proceeded to the production floor to operate the ultrasonic assembly system. During the morning and afternoon 10 minute breaks, the employee took the vest off and placed it over their chair. During the employee lunch break, the vests were collected by the researcher and instruments checked for battery usage and running usage. After the 30 minute lunch break the vests were returned to the employee to wear for the remainder of their shift. After the 8 hour employee workshift the vests were returned to the researcher and the data collected from the instruments was uploaded to the computer system.

3.5 Data Analysis

3.5.1 Statistical Analysis

The null hypothesis for the paired t-test evaluated whether the differences of the means for the matched vales were zero. A Student's t-test for paired data was used to compare Type 1 and Type 2 Quest NoisePro noise dosimeter data for each sample day and to compare the average sound-pressure level measured by each dosimeter. The student's t-test was used to identify the samples whose means were significantly different using a critical value determined for $\alpha = 0.05$. KaleidaGraph version 4.0 was used to calculate the student's t-test. The correlation of Type 1 and Type 2 measurements were also examined graphically. A correlation probability less than 0.05 indicated that the data sets were significantly correlated.

3.5.2 Time-Weighted Average Sound-Pressure Level

The time-weighted average sound intensities for the dosimeters and real-time analyzers (at 10,000 Hz, 12,500 Hz, 16,000 Hz, and 20,000 Hz) were calculated to determine employee noise exposure for comparison to ACGIH and OSHA regulations:

$$\text{TWA sound intensity} = \frac{\sum \text{sound intensity during time n} \bullet \text{time n}}{\sum \text{time n}} \quad \text{(Equation 3.5a)}$$

$$\text{where sound intensity} = 10^{\frac{dB}{10}} \quad \text{(Equation 3.5b)}$$

The average sound-pressure level (SPL), Leq, was determined for each sample set based on the exchange rate that the instrument was set to. For a 3 dB exchange rate:

$$TWA\ \ SPL\,(decibel) = 10 \bullet Log_{10}(\text{sound intensity}) \quad \text{(Equation 3.5c)}$$

where the sound intensity is equal to equation 3.5b.

The average sound-pressure level (SPL), Leq, for a 5 dB exchange rate was calculated using:

$$TWA\ \ SPL\,(decibel) = 16.61 \bullet Log_{10}(\text{sound intensity}) \quad \text{(Equation 3.5d)}$$

$$\text{where sound intensity} = 10^{\frac{dB}{16.61}} \quad \text{(Equation 3.5e)}$$

The TWA was used to calculate the dose for each dosimeter and real-time analyzer to determine if the noise exposure experienced by the employee was in compliance with OSHA regulations and ACGIH guidelines. Criteria for OSHA engineering and administrative controls include only noise exposure greater than a threshold of 90 dBA and a dose that is greater than 1.0 (100%). The OSHA hearing conservation program criteria includes only noise exposure greater than a threshold of 80 dBA and a dose greater than 0.5 (50%). OSHA regulations are based on a criterion SPL of 90 dBA for 8 hours and an exchange rate of 5 dB. The ACGIH TLV for noise uses an 85 dBA criterion for 8 hours with an 80 dBA threshold and a doubling value of 3 dB. The equation 3.5f was used to calculate the dose.

$$Dose = \sum \frac{Exposure\ time\ at\ x\ dBA}{Permitted\ time\ at\ x\ dBA} \qquad \text{(Equation 3.5f)}$$

The permitted times are presented in Appendix A. The PEL times can be calculated using equation 3.5g and the ACGIH TLV times can be calculated using equation 3.5h.

$$OSHA\ PEL \rightarrow Time(\text{minutes}) = \frac{480}{2^{(SPL-90)\div 5}} \qquad \text{(Equation 3.5g)}$$

$$ACGIH\ TLV \rightarrow Time(\text{minutes}) = \frac{480}{2^{(SPL-85)\div 3}} \qquad \text{(Equation 3.5h)}$$

Chapter IV: Results

The purpose of this study was to compare Type 1 to Type 2 noise dosimeters for monitoring employee exposure to ultrasound emitted from ultrasonic welders. This was conducted by measuring employee noise exposure during 8 work shifts at Company XYZ using Quest NoisePro Type 1 and Type 2 noise dosimeters, a Larson Davis RTA, and a Quest RTA.

4.1 Average Sound-Pressure Levels

4.1.1 Sound-Pressure Level Exposures Measured by Dosimeters

The average sound-pressure level for each meter was calculated using the one-second TWAs measured for each sample date (equation 3.5a and 3.5b). The average sound-pressure level is affected by the exchange rate selection for the instrument. Therefore, equation 3.5c was used to determine the average sound-pressure level for the initial dosimeter data sampling using a 3 dB exchange rate. For the later dosimeter data sets, equations 3.5d and 3.5 e were used based on a 5 dB exchange rate (OSHA parameters). The real-time analyzers (RTAs) that were used always logged data using a 3 dB exchange rate. The average sound-pressure levels measured ranged from 74.2 dBA to 87.9 dBA for the Type 1 dosimeter and from 76.3 dBA to 87.8 dBA for the Type 2 dosimeters (table 4.1). The average sound-pressure level for the Type 1 was ±2 dB of the average sound-pressure level for the Type 2 dosimeter except for set B on June 30, 2008; August 20, 2008; and September 19, 2008 (table 4.1).

Table 4.1. The average sound-pressure level measured by the dosimeters.

Sample Date	Dosimeter	Type 1 (dBA)	Type 2 (dBA)
26-Jun-08			
	Set A	81.4	80.1
	Set B	79.9	81
	Set C	77.4	77.6
27-Jun-08			
	Set A	78.2	79.1
	Set B	84	83.7
	Set C	80.5	79.7
30-Jun-08			
	Set A	87.9	87.8
	Set B	78.3	83.4
	Set C	85.7	85.4
19-Aug-08			
	Set B	74.2	76
20-Aug-08			
	Set B	84	79.1
28-Aug-08			
	Set B	76.3	77.7
19-Sep-08			
	Set B	85.1	82.5
2-Oct-08			
	Set B	84.8	84.5

4.1.2 Sound-Pressure Level Overexposures

Regulatory noise exposure levels set by OSHA (Department of Labor, 1971), as well as guidelines set by ACGIH (ACGIH, 2006), are used to aid the employer in assessing worker exposure to occupational noise. The OSHA Permissible Exposure Limits (PEL) for audible noise uses a criterion level of 90 dBA for 8 hours. The criteria for engineering and administrative controls is a dose of 1.0 using a 90 dBA threshold. The criteria for hearing conservation is a dose of 0.5 based on an 80 dBA threshold. ACGIH Threshold Limit Value (TLV) for noise has a criterion level of 85 dBA for 8 hours using an 80 dBA threshold. Equations 3.5f and 3.5g were used to calculate worker exposures based on the OSHA Engineering and Hearing Conservation criteria. Equations 3.5f and 3.5h were used to calculate worker exposures based on the ACGIH

TLV criteria. The OSHA Hearing Conservation criterion was exceeded on September 19, 2008 and the ACGIH criteria was exceeded on June 30, 2008; August 20, 2008; September 19, 2008; and October 2, 2008 (table 4.2). The OSHA Hearing Conservation dose values were much lower than would be expected given the average sound-pressure levels calculated for each shift. Lower values occur for dose calculations using the OSHA 5 dBA exchange rate algorithm in workplaces that have rapidly changing sound-pressure levels (Earshen, 2003). The sound-pressure level exposures during ultrasonic welding would appear to be better measured by the 3 dB exchange rate ACGIH dose values than the OSHA dose values.

The average sound-pressure levels for the one-third octave band ultrasonic frequencies were calculated (table 4.3). Noise measurements on August 20, 2008 and September 19, 2008 exceeded the ACGIH TLVs for ultrasound at 10 kHz (88 dB) and 20 kHz (94 dB).

Table 4.2. Calculated sound-pressure levels and dose[1] based on OSHA and ACGIH criteria for dosimeters.

Sample Date	Dosimeter	Duration (hours)	Leq (dB)	OSHA Engineering	OSHA Hearing Conservation	ACGIH
26-Jun-08						
	1-8	8.15	81.4	0.06	0.13	0.40
	2-35008	8.14	80.1	0.04	0.07	0.28
	1-9	7.98	79.9	0.03	0.07	0.22
	2-13	7.98	81.0	0.04	0.09	0.30
	1-10	8.24	77.4	0.001	0.03	0.06
	2-10	8.25	77.6	0.001	0.03	0.06
27-Jun-08						
	1-8	7.98	78.2	0.001	0.05	0.10
	2-35008	7.96	79.1	0.002	0.07	0.13
	1-9	7.84	84.0	0.08	0.20	0.69
	2-13	7.86	83.7	0.08	0.20	0.65
	1-10	7.91	80.5	0.02	0.06	0.26
	2-10	7.88	79.7	0.02	0.07	0.19
30-Jun-08						
	1-8	8.57	87.9	0.21	0.31	2.0*
	2-35008	8.56	87.8	0.18	0.29	2.0*
	1-9	7.01	78.3	0.07	0.12	0.73
	2-13	7.91	83.4	0.08	0.15	1.2*
	1-10	8.56	85.7	0.16	0.26	1.2*
	2-10	8.56	85.4	0.17	0.26	1.1*
19-Aug-08						
	1-9	7.27	74.2	0.01	0.09	0.20
	2-13	7.27	76.0	0.01	0.11	0.26
20-Aug-08						
	1-9	7.71	84.0	0.28	0.41	2.5*
	2-13	7.70	79.1	0.09	0.20	0.76
28-Aug-08						
	1-9	8.09	76.3	0.06	0.14	0.42
	2-13	8.08	77.7	0.05	0.17	0.44
19-Sep-08						
	1-9	7.85	85.1	0.39	0.54*	4.0*
	2-13	7.85	82.5	0.17	0.33	1.3*
2-Oct-08						
	1-9	7.57	84.8	0.31	0.45	7.2*
	2-13	7.75	84.5	0.27	0.44	6.0*

*Dose exceeds OSHA or ACGIH dose criteria

1. Dose values were calculated using the one-second SPL exposure data.

Table 4.3. Calculated sound-pressure levels (dB) for the Real-Time Analyzers.

Sample Date	Duration (hours)	Frequency (Hz) 10	12.5	16	20
26-Jun-08					
Larson Davis	2.86	65.3	63.1	61.8	80.8
Quest	5.08	83.3	72.4	72.4	75.1
27-Jun-08					
Larson Davis	2.27	62.5	62.2	62.4	83.0
Quest	6.67	69.7	61.4	59.9	72.9
30-Jun-08					
Larson Davis	4.84	85.4	76.4	87.2	87.2
19-Aug-08					
Larson Davis	7.44	78.5	72.3	68.6	82.8
20-Aug-08					
Larson Davis	6.99	90.0*	62.0	59.5	87.4
28-Aug-08					
Larson Davis	7.60	73.9	64.5	68.1	90.6
19-Sep-08					
Larson Davis	7.65	94.9*	76.4	76.2	99.7*
2-Oct-08					
Larson Davis	6.60	79.6	68.9	70.1	91.3

*denotes overexposure of ACGIH TLVs for ultrasound.

4.1.3 Ultrasound Ceiling Value Overexposure

The Larson Davis and Quest RTA maximum sound-pressure levels for the duration of the workshift were analyzed to determine overexposure of the 105 dB ceiling value (Appendix C). Evaluating the maximum noise levels measured by the Quest RTA, similar sound-pressure levels were detected amongst all of the frequency bands. The 10 kHz and 20 kHz frequency bands were found to be the most dominate during the interval measurements (figure 4.1). Further analysis of the maximum sound-pressure level measured by the Larson Davis showed a similar pattern between the 10 kHz and 20 kHz frequency bands as the Quest RTA (figure 4.2).

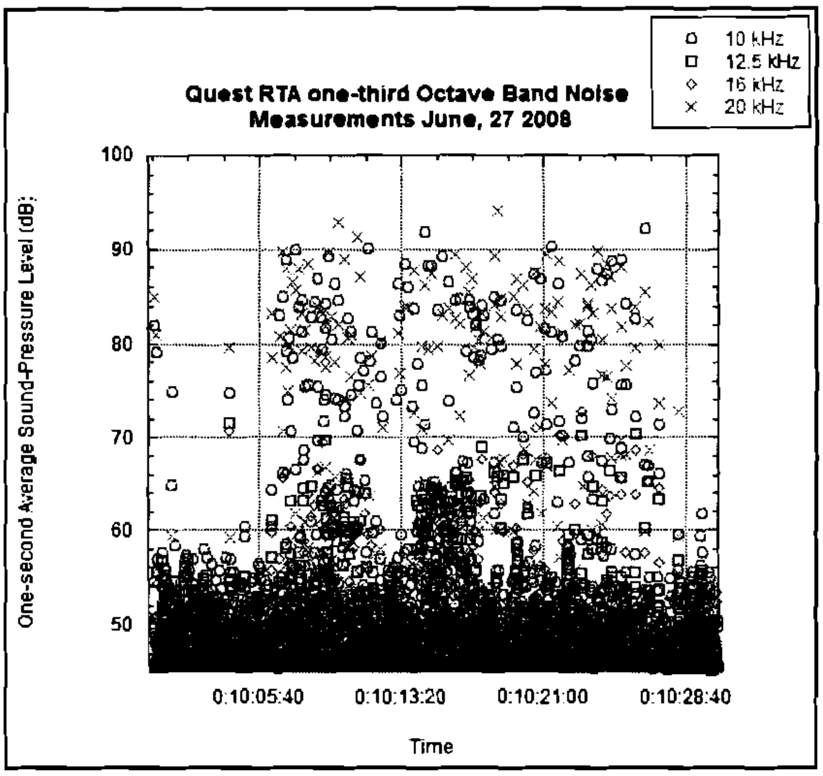

Figure 4.1. Noise patterned observed for all frequency bands for one-half hour.

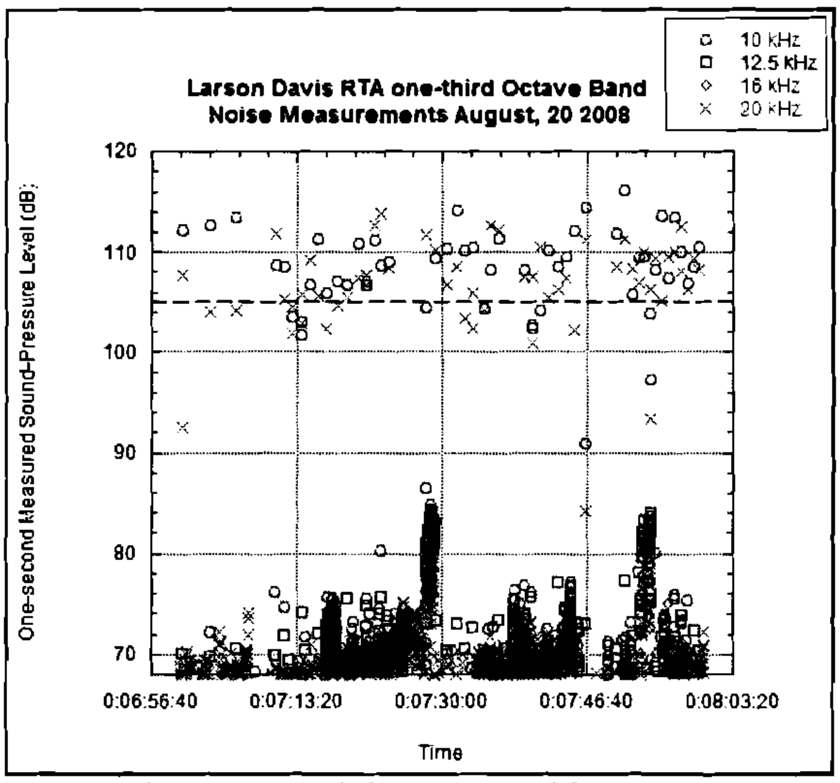

Figure 4.2. Noise pattern observed for each frequency band for one hour, dashed line represents SPL (dB) exceeding ACGIH ceiling limit of 105 dB.

4.1.4 Comparison of Type 1 and Type 2 Dosimeters for Measuring Ultrasound

A two step process was used to evaluate the performance of Type 1 versus Type 2 noise dosimeters for the measurement of ultrasonic noise exposure. The first step evaluated whether the sound-pressure level measurements recorded by the Type 1 dosimeter was equal to the measurements recorded by the adjacent Type 2 dosimeter by performing a Student's t-test for paired data. Eleven of the fourteen measurements were significantly different (table 4.4).

The second step of the process evaluated the relationship between the measurements to determine if the values recorded the response to sound at the same time interval. Linear curve fits of the data plots for each dosimeter set were used to calculate the linear correlation coefficient (Appendix D). The coefficient ranged from 0.12 to 0.84 (table 4.4). The closer the value is to 1.0, the closer the two sets of data are correlated. The wide scatter of the data points on the graph suggest that the matching of the dosimeter clocks in the paired dosimeters did not provide simultaneous recordings of the noise.

Another evaluation was to determine if each day's average SPL measured by the Type 1 dosimeter was the same as the average SPL measured by the Type 2 dosimeter. There was not a statistically significant difference between the average sound-pressure levels calculated for the Type 1 and the average sound-pressure levels calculated for the Type 2 dosimeters (table 4.5).

Table 4.4. Paired t-test of Type 1 and Type 2 noise dosimeter one-second sound-pressure levels and their linear correlation coefficient.

Sample Date	Dosimeter	Difference Between Means	P-Value	Correlation Probability	R
26-Jun-08					
	1-8 2-35008	-0.868	<0.0001*	<0.0001	0.29
	1-9 2-13	-0.858	<0.0001*	<0.0001	0.63
	1-10 2-10	-0.269	<0.0001*	<0.0001	0.81
27-Jun-08					
	1-8 2-35008	-0.831	<0.0001*	<0.0001	0.84
	1-9 2-13	-0.324	<0.0001*	<0.0001	0.51
	1-10 2-10	-0.028	0.1753	<0.0001	0.81
30-Jun-08					
	1-8 2-35008	0.034	0.435	<0.0001	0.50
	1-9 2-13	-0.34	<0.0001*	<0.0001	0.52
	1-10 2-10	-0.193	<0.0001*	<0.0001	0.62
19-Aug-08					
	1-9 2-13	-8.08	<0.0001*	<0.0001	0.12
20-Aug-08					
	1-9 2-13	8.36	<0.0001*	<0.0001	0.34
28-Aug-08					
	1-9 2-13	-10.01	<0.0001*	<0.0001	0.21
19-Sep-08					
	1-9 2-13	-0.375	0.1677	<0.0001	0.41
2-Oct-08					
	1-9 2-13	-7.85	<0.0001*	<0.0001	0.70

*denotes statistically different P-value at $\alpha = 0.05$

Table 4.5 Paired t-test of the average sound-pressure level recorded by the dosimeters.

	Type 1	Type 2
Count	14	14
Mean	81.2643	81.2143
Variance	16.6163	11.6613
Standard Deviation	4.07631	3.41487
Standard Error	1.08944	0.912662
Mean Difference	0.0500009	
Degrees of Freedom	13	
t-value	0.067409	
t-probability	0.9473	
Correlation	0.73904	
Correlation Probability	0.002529	

4.2 Relationship between Ultrasound and the Welded Component

The initial sampling for ultrasound did not evaluate the component being welded. However, the later research did consider the type of component that was being welded each day of sampling. During sampling, both plastic to plastic and metal to plastic components were welded (Appendix E contains pictures of the components welded for each sample date).

The average sound-pressure levels presented in table 4.6 were higher for the parts whose components extended above the welding jig. The dispensing head (welded August 20, 2008), the base exhalation (welded September 19, 2008), and the filter head assembly (welded October 2, 2008).

Table 4.6. Recorded noise levels related to welded components.

Sample Date	Welded Component	Dosimeter Leq (dB)		RTA Leq (dB)	
		Type 1	Type 2	10 kHz	20 kHz
Aug. 19, 2008	Cover Manifold	74.2	76.0	78.8	82.8
Aug. 20, 2008	Dispensing Head	84.0	79.1	90.0	87.4
Aug. 28, 2008	Port Housing	76.3	77.7	73.9	90.6
Sep. 19, 2008	Base Exhalation	85.1	82.5	94.9	99.7
Oct. 2, 2008	Filter Head Assembly	84.8	84.5	79.6	91.3

Chapter V: Discussion

This study evaluated the effectiveness of Type 1 and Type 2 noise dosimeters for monitoring employee exposure to ultrasound emitted from ultrasonic welders. The measurements were conducted over a period of 8 sample days at Company XYZ.

5. 1 Limitations

The limitations of the study are as follows:

- The measurement of ultrasonic noise was not evaluated for all possible types of joining components. Exposures may vary with the size and shape of the materials being welded together.
- The research conducted measured ultrasonic noise exposure due to ultrasonic welding at 20 kHz at one facility. Differences due to the facility layout and ultrasonic noise sources were not evaluated.

5.2 Conclusions

5.2.1 Employee Noise Exposure – Average Sound-Pressure Level

The average sound-pressure levels experienced by ultrasonic welder operators ranged from 74.2 dBA to 87.9 dBA.

5.2.2 Employee Noise Exposure – Comparison to Standards

5.2.2.1 OSHA PEL and ACGIH TLV for Noise

No noise exposure exceeded the OSHA Engineering criteria. The OSHA Hearing Conservation criteria was exceeded by 1 out of 28 measurements. The ACGIH TLV for noise was exceeded by 10 out of 28 measurements. A Hearing Conservation Program should be implemented based on the calculated OSHA dose overexposure of 0.5 on September 19, 2008.

5.2.2.2 ACGIH TLV for Ultrasound

Several of the average sound-pressure level for 10 kHz and 20 kHz third-octave bands exceeded the TLV recommendations. Most sample days had measurements that exceeded the ceiling limit TLV of 105 dB. This suggests frequent overexposure to ultrasound.

5.2.3 Efficacy of Noise Instruments to Measure Ultrasound

5.2.3.1 Type 1 versus Type 2 Dosimeters

There was no advantage to using a Type 1 dosimeter over a Type 2 dosimeter. While the recorded noise measurements were statistically different, the time weighted average sound-pressure levels were not. The differences in the recorded sound pressures at each one-second interval could be caused by some aspect of the data recording, air flow around the microphone, or the employee bumping the microphone. These errors would cause a variation in the decibel reading per interval and an overall effect on the statistical analysis of the interval measurements.

It was thought that the enhanced ability of the Type 1 microphone to measure sound between 10 kHz and 20 kHz over the Type 2 microphone would result in higher sound-pressure levels being recorded by the Type 1 dosimeter. The results of this study demonstrated no significant difference between the average sound-pressure levels by Type 1 and Type 2 dosimeters. In this study the overall average sound-pressure level recorded by the Type 2 dosimeters, 81.21 dBA, was essentially the same as the Type 1 dosimeters, 81.26 dBA. The lack of influence of the ultrasonic noise on the average sound-pressure level may have resulted from a combination of the short time intervals of the welds and the A-weighting reduction of high frequency sound.

5.2.3.2 Real-Time Analyzers

The RTA appears to be the best instrument for assessing employee exposure to ultrasound. This is because the RTA was used in the flat frequency response which allows for equal detection of high frequency sound across all frequencies. Whereas the NoisePro dosimeters were limited to A-scale measurements which discount the ultrasonic welder's high frequency sound experienced by the operators.

5.2.4 Relationship between Ultrasound and the Welded Component

Noise levels were higher during the welding of parts whose components extended above the welding jig.

5. 3 Recommendations

5.3.1 Applicability of Sampling Method in Other Industries

The American National Standards Institute has standards for sound measuring instruments, ANSI S1.25-1991 and ANSI S1.4-1983. Type 1 instruments are used when accurate evaluation and precision is needed for field use or during research. Type 2 instruments are used for general purposes when high frequency noise is not present (ANSI, 1983). In this study, noise exposures experienced by operators of 20 kHz ultrasonic welders were evaluated using Type 1 and Type 2 noise dosimeters. No difference was found between the average A-scale sound-pressure levels recorded by the Type 1 and Type 2 noise dosimeters. Type 2 dosimeters appear to be adequate for assessment of compliance with OSHA regulations. Evaluation with respect to ACGIH TLVs for ultrasound requires a Type 1 RTA with a 1/3 octave band filter. The one-second sound-pressure levels for the 1/3 octave frequency bands enables the identification of exposures above the ceiling value criteria.

Consideration should also be given to the parameters used for each noise instrument when applying this sampling method to other ultrasonic sources. The initial and later evaluations of ultrasonic noise exposure had different parameters set for the noise dosimeters. After calculating TWA SPLs and dose exposures, it was found that the latter parameters underestimated the average sound-pressure levels. The following parameters are recommended since these parameters will provide values greater than or equal to the values determined using the OSHA criteria, they would be satisfactory for determining regulatory compliance.

The following parameters should be set when using either a Type 1 or Type 2 noise dosimeter:

- Response – Fast
- Frequency Weighting – A
- Threshold – OFF
- Exchange Rate – 3 dB

The following parameters should be set when using a Real-Time Analyzer:

- Response – Fast
- Frequency Weighting – Flat
- Threshold – OFF
- Exchange Rate – 3 dB

5.3.2 Controls to Reduce Ultrasound Noise Exposure

Based on the evaluation of noise exposure during the ultrasonic welding of plastic to plastic and metal to plastic components several workers experienced exposure to noise and ultrasound. These exposures exceeded the OSHA criteria for inclusion in the Hearing Conservation Program and the ACGIH 105 dB ceiling criteria for ultrasound. Operators of the welders were observed wearing personal hearing protectors. Engineering controls such as sound enclosures over the welders may also provide a reduction in noise exposures experienced by the employees at Company XYZ.

5.4 Further Research

The limitations that were encountered in this study should be taken into consideration before conducting future research on this topic. An improved matching of the sound-pressure levels recorded by the paired dosimeters is needed. Investigations at facilities with higher noise levels may aid in the comparison of Type 1 to Type 2 dosimeter measurements. Also, research evaluating the noise reduction that sound enclosures provide when used on ultrasonic welders would be valuable. Lastly, smaller Type 1 microphones for the real-time analyzer meters would be more convenient for the employees to wear and allow easier mounting of the unit in the vicinity of the worker's hearing zone.

References

Acton, W. I. (1974). The effects of industrial airborne ultrasound on humans. *Ultrasonics, 12,* 124-128.

Acton, W.I. (1983). Exposure to industrial ultrasound: Hazards, appraisal and control. *Journal of Social and Occupational Medicine, 33,* 107-113.

Alberti, Peter. (2001). The anatomy and physiology of the ear and hearing. In B. Goelzer, C. Hansen, & G. Sehrndt (Eds.), *Occupational exposure to noise: Evaluation, prevention, and control* (pp. 53 -62). Geneva: World Health Organization. Retrieved July 6, 2008, from http://www.who.int/occupational_health/publications/noise4.pdf

American Conference of Governmental Industrial Hygienists. (2001). *Ultrasound.* Cincinnati, OH: ACGIH.

American Conference of Governmental Industrial Hygienists. (2006). *Noise.* Cincinnati, OH: ACGIH.

American Conference of Governmental Industrial Hygienists. (2007). *History.* Retrieved December 14, 2008 from, http://www.acgih.org/about/history.htm

American National Standards Institute. (1983). *American national standard specification for sound level meters.*

Babisch, Wolfgang. (2005). Noise and health. *Environmental Health Perspective, 113,* 1, A14-A15. Retrieved October 12, 2008 from, http://www.pubmedcentral.nih.gov/articlerender.fcgi?article=1253720

Baker, David E. (1993). *Noise: The invisible hazard.* Retrieved October 12, 2008, from http://www.cdc.gov/nasd/docs/d000801-d000900/d000882/d000882.html

Berger, E. H. (1996). Protection for infrasonic and ultrasonic noise exposure. *EARLOG,* (14), 1-2.

Bly, Stephen and Deirdre, Morison. (1991). *Guidelines for the safe use of ultrasound: Part II-industrial and commercial applications.* Ottawa, Canada: Canadian Communication Group – Publishing.

Branson Ultrasonics Corporation. (1999). *Branson 2000 series.* Retrieved November 24, 2008, from http://www.branson-plasticsjoin.com/pdf/2000d-aed.pdf

Chan, Apple. (2008). *Introduction to sound.* Retrieved August 12, 2008, from http://personal.cityu.edu.hk/~bsapplec/spectrum.htm

Concha-Barrientos, M., Campbell-Lendrum, D., & Steenland, K. (2004). Occupational noise: Assessing the burden of disease from work-related hearing impairment at national and local levels. In A. Pruss-Ustun, D. Campbell-Lendrum, C. Corvalan, A. Woodward (Series Ed.), *Environmental Burden of Disease.* (Series No. 9, pp. 1-40). Geneva, World Health Organization.

Cowan, J. (1994). *Handbook of environmental acoustics.* New York, NY: Van Nostrand Reinhold.

Crabtree, R. B. & Behar, A. (2000). Measurement of hearing protector insertion loss at ultrasonic frequencies. *Applied Acoustics, 59,* 287-299.

Damongeot, A. and Andre, G. (1988). Noise from ultrasonic welding machines: Risks and prevention. *Journal of Applied Acoustics, 25,* 49-66.

Danielson, R. W. (2008). *Hearing loss prevention: Prevention of hearing loss from noise exposure.* Retrieved June 21, 2008, from http://www.betterhearing.org/hearing_loss_prevention/indexdetail.cfm

Department of Labor. Occupational noise exposure standard. Title 29, chapter XVII, Part 1910, Subpart G, 1910.95. Federal Register 1971; 36:10518.

Department of Labor/OSHA. Occupational noise exposure: hearing conservation amendment, final rule. Federal Register 1983; 48 (46):97738-85.

Doumandis, C. & Gao, Y. (2004). Mechanical modeling of ultrasonic welding. *Welding Journal, 83*(4), 140-146.

Earshen, John, J. (2003). Sound measurement: Instrumentation and noise descriptors. In E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (Eds.), *The noise manual* (5^{th} ed., text rev.) (pp. 43-98). Indiana: American Industrial Hygiene Association.

Fulmer, M. (2001). *Noise (Hearing Conservation) Requirements.* Retrieved August 3, 2008, from www.osp.state.nc.us/divinfo/frames/divisions/rcs/hygiene/NOISEZ.pdf

Giardino, Dennis A., Seiler, John P., Yen, Timothy Y. (1978). *MSHA test procedures and applicability criteria for noise dosimeters.* United States: Mine Safety and Health Administration.

Gibson, Stuart W. (1997). *Advanced welding.* Hampshire, England: MacMillan Press.

Goines, Lisa and Hagler, Louis. (2007). Noise pollution: A modern plague. *Southern Medical Journal, 100*, 287-294.

Grzesik, J. & Pluta, E. (1983). High-frequency hearing risk of operators of industrial ultrasonic devices. *International Archives of Occupational and Environmental Health, 53*, 77-88.

Grzesik, J. & Pluta, E. (1986). Dynamics of high-frequency loss of operators of industrial ultrasonic devices. *International Archives of Occupational and Environmental Health, 57*, 137-142.

Hanson, C. (2001). Fundamentals of acoustics. In B. Goelzer, C. Hansen, & G. Sehrndt (Eds.), *Occupational exposure to noise: Evaluation, prevention, and control* (pp. 23-52)

Hearing Foundation of Canada. (2007). *Noise, noise-induced hearing loss and prevention.* Retrieved July 8, 2008 from, http://hearingfoundation.ca/cms/en/noisenoiseinducedhearingloss.aspx

Health Information Publications. (2004). *What other conditions can cause hearing loss?* Retrieved December 14, 2008 from, http://www.ehealthmd.com/library/hearingloss/HL_conditions.html

Henderson, D. and Hamernik, R.P. (1986). Impulse noise: Critical review. *Journal of the Acoustical Society of America, 80*(2), 569-584.

Herman, Bruce and Powell, David. (1981). *Airborne ultrasound: Measurement and possible adverse health effects.* U.S. Department of Health and Human Services. Rockville, MD

Howard, C. Q., Hansen, C. H., & Zander, A. C. (2005). A review of current ultrasound exposure limits. *Proceedings of Acoustics.* Busselton, Western Australia.

Industrial Acoustics Company. (1989). *Noise control reference handbook.* Bronx, NY: Industrial Acoustics Company.

Johnson, D.L., Papadopoulos, P., Takala, J., Watfa, N. (2001). Exposure criteria, occupational exposure levels. In B. Goelzer, C. Hansen, & G. Sehrndt (Eds.), *Occupational exposure to noise: Evaluation, prevention, and control* (pp. 79 -102). Geneva: World Health Organization. Retrieved July 6, 2008, from http://www.who.int/occupational_health/publications/noise4.pdf

Kardous, Churci A., Willson, Robert D., Hayden, Charles S. (2002). *Limitations of integrating impulse noise when using dosimeters.* Retrieved October 29, 2008 from http://www.cdc.gov/niosh/topics/noise/pubs/presentations/dosimeters1.swf

Knight, R.D., Baguley, D.M. (2007). Physical characteristics of sound. In L. Luxon and D. Prasher (Eds.), *Noise and its effects* (pp. 1-12). England: Whurr Publishers Limited.

Larson Davis. (2006). *Sound level meter and real-time analyzer.* Retrieved November 24, 2008 from http://www.larsondavis.com/Downloads/824_0606.pdf

Lawton, B.W. (2001). *Damage to human hearing by airborne ultrasound of very high frequency or ultrasonic frequency.* Norwich: Crown.

Leighton, Timothy G. (2007). What is ultrasound? *Progress in Biophysics and Molecular Biology, 93,* 3-83.

Malchaire, J. (2006). *Sound measuring instruments.* Retrieved November 28, 2008 from http://www.who.int/occupational_health/publications/noise6.pdf

McLaughlin, D. (1996). OSHA technical manual, Sec. II: Health hazards. *Noise measurement* (pp. 1-20). Retrieved June 18, 2008, from http://www.cbs.state.or.us/osha/pdf/techman/noise.pdf

Michael, Paul, L and Michael, Kevin, L. (2006). Noise Measurement. In R. Sataloff & J. Sataloff (Eds.), *Occupational hearing loss* (3rd edition) (pp. 618-639). Florida: Taylor and Francis Group.

National Institute of Occupational Safety and Health. (1972). *A recommended standard for occupational exposure to noise.* Cincinnati, OH: U.S. Department of Health and Human Services.

National Institute of Occupational Safety and Health. (1998). *Criteria for a recommended standard: Occupational noise exposure.* Cincinnati, OH: U.S. Department of Health and Human Services.

National Institute of Occupational Safety and Health; National Safety Council. (2008). *Noise and hearing loss prevention: Work-related hearing loss.* Retrieved June 12, 2008, from http://www.cdc.gov/niosh/topics/noise/abouthlp/workerhl.html

Occupational Safety and Health Act of 1970. Public Law 91-596, 91st Congress, S. 2193. December 29, 1970.

Ostergaard, Paul B. (2003). Physics of sound and vibration. In E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (Eds.), *The noise manual* (5th ed., text rev.) (pp. 568-595). Indiana: American Industrial Hygiene Association.

Parrack, Horrace O. (1966). Noise induced hearing loss. *International Journal of Audiology, 5,* 295-308.

Paul, Kelly. (2006). *Department of Defense Hearing Conservation.* Retrieved December 14, 2008 from, http://www-nehc.med.navy.mil/occmed/HCToolbox.htm#Mod1

Pawlaczyk-Luszczynska, M., Dudarewicz, A., Sliwinska-Kowalska, M., (2007). Theoretical predictions and actual hearing threshold levels in workers exposed to ultrasonic noise of impulsive character: A pilot study. *International Journal of Occupational Safety and Ergonomics, 13*(4), 409-418.

Quest Technologies, Inc. (2005). *NoisePro: Noise dosimeter owner's manual.* Retrieved June 18, 2008, from http://www.quest-technologies.com/PDFs/Manuals/Noise/NoisePro.pdf

Quest Technologies, Inc. (2008). *NoisePro brochure.* Retrieved November 24, 2008, from http://www.quest-technologies.com/PDFs/Brochures/Noise/NoisePro.pdf

Quest Technologies, Inc. (2008). *Preliminary technical specifications.* Retrieved November 24, 2008, from http://quest-technologies.com/Sound/Advanced/Spro_SE_DL/SE_DL_pdf/SProSE_DL_Specs.pdf

Robinson, G.S. and Casali, J.G. (2003). Speech communication and signal detection in noise. In E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (Eds.), *The noise manual* (5th ed., text rev.) (pp. 568-595). Indiana: American Industrial Hygiene Association.

Rotheiser, J. (2004). Ultrasonic welding. In *Joining of plastics: Handbook for designers and engineers* (2nd ed., pp. 462-505). Munich: Hanser.

Sataloff, Robert T. and Sataloff, Joseph. (2006). Occupational hearing loss: An overview. In R. Sataloff & J. Sataloff (Eds.), *Occupational hearing loss* (3rd edition) (pp. 1-2). Florida: Taylor and Francis Group.

Sataloff, Robert T. and Sataloff, Joseph. (2006). The physics of sound. In R. Sataloff & J. Sataloff (Eds.), *Occupational hearing loss* (3rd edition) (pp. 4-17). Florida: Taylor and Francis Group.

Schuder, M., (2006). *Waves and superposition.* Physical chemistry laboratory manual. (pp.42-45)

Shapiro, Sydney. (1991). *The dormant noise control act and options to abate noise pollution.* Retrieved October 13, 2008, from http://www.nonoise.org/library/shapiro/shapiro.htm

Smith, Andrew. (1990). Noise, performance efficiency and safety. *International Archives of Occupational and Environmental Health, 62*, 1-5.

Smith, Andrew. (1998). The World Health Organisation and the prevention of deafness and hearing impairment caused by noise. *Noise & Health, 1*(1), 6-12.

Sulkowski, Wieslaw, J. (2007). Occupational noise. In L. Luxon and D. Prasher (Eds.), *Noise and its effects* (pp. 397-434). England: Whurr Publishers Limited.

Suter, Alice H. (1991). *Noise and its effects*. Retrieved October 13, 2008 from, http://www.nonoise.org/library/suter/suter.htm#physical

System 824 precision sound level meter and real time analyzer: Reference manual. Provo, Utah: Larson Davis. (2006).

Takeda, Shintaro, Morioka, Ikuharu, Miyashita, Kazuhisa, Okumura, Akeharu, Yoshida, Yoshiaki, Motsumoto, Kenji. (1992). Age variation in the upper limit of hearing. *European Journal of Applied Physiology, 65*, 403-408.

Technical Learning College. (2005). *Hearing conservation.* Retrieved June 21, 2008, from http://www.abctlc.com/courses/HearingConservation.PDF

Toronto Public Health. (2000). *Health effects of noise.* Toronto: City of Toronto.

U.S. Bureau of Labor Statistics, U.S. Department of Labor, (2005). Retrieved June 14, 2008, from http://www.bls.gov/iif/oshwc/osh/os/osbl0014.pdf

U.S. Department of Defense. (2007). *Hazardous noise and deployment: Information for service members and their families.* Retrieved June 17, 2008, from deploymenthealthlibrary.fhp.osd.mil/accessLog.jsp?prodid=286

U.S. Department of Labor. Occupational Safety & Health Administration. (2007). *Noise exposure computation – 1910.95 App A.* Retrieved November 24, 2008, from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9736

U.S. Department of Labor. Occupational Safety & Health Administration. (2008). OSHA technical manual. *Noise and hearing conservation* (section III, chap. 5). Retrieved May 21, 2008, from http://www.osha.gov/dts/osta/otm/noise/index.html

Valoski, Michael P., Seiler, John P., Crivaro, Michael A., Durkt, George. (1995). *Comparison of noise exposure measurements conducted with sound level meters and noise dosimeters under field conditions.* United States: Mine Safety and Health Administration.

Ward, Dixon W., Royster, Larry, H., Royster, Julia D. (2003). Anatomy and physiology of the ear: Normal and damaged hearing. In E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (Eds.), *The noise manual* (5th ed., text rev.) (pp. 102-121). Indiana: American Industrial Hygiene Association.

Ward, Dixon W., Royster, Larry, H., Royster, Julia D. (2003). Auditory and nonauditory effects of noise. In E.H. Berger, L.H. Royster, J.D. Royster, D.P. Driscoll, and M. Layne (Eds.), *The noise manual* (5th ed., text rev.) (pp. 123-144). Indiana: American Industrial Hygiene Association.

Wiernicki, C., Karoly, W. (1985). Ultrasound: Biological effects and industrial hygiene concerns. *American Industrial Hygiene Association Journal, 46(9),* 488-496.

World Health Organization. (1980). *Noise* International Programme on Chemical Safety Environmental Health Criteria 12). Geneva, Switzerland: Author. Retrieved September 29, 2008, from http://www.inchem.org/documents/ehc/ehc/ehc012.htm

World Health Organization. (1982). *Ultrasound.* (International Programme on Chemical Safety Environmental Health Criteria 22). Geneva, Switzerland: Author. Retrieved September 19, 2008, from http://www.inchem.org/documents/ehc/ehc/ehc22.htm

World Health Organization. (1997). Prevention of noise-induced hearing loss. *Strategies for prevention of deafness and hearing impairment.* (Series 3 pp. 1-55). Geneva: World Health Organization. Retrieved September 28, 2008, from http://www.who.int/pbd/deafness/en/noise.pdf

World Health Organization. (1999). *Guidelines for community noise.* Retrieved August 12, 2008, from http://www.who.int/docstore/peh/noise/guidelines2.html

World Health Organization. (2001). *Occupational and community noise.* Retrieved September 26, 2008, from http://www.who.int/mediacentre/factsheets/fs258/en/

Appendix A: Regulations and Guidelines

Table A-1. TLVs for Audible Noise. From ACGIH®, *2008 TLVs® and BEIs®* (p. 122), Ohio: ACGIH. Copyright 2008 by American Conference of Governmental Industrial Hygienists. Reprinted with permission.

	Duration per Day	Sound Level dBA
Hours	24	80
	16	82
	8	85
	4	88
	2	91
	1	94
Minutes	30	97
	15	100
	7.50	103
	3.75	106
	1.88	109
	0.94	112
Seconds	28.12	115
	14.06	118
	7.03	121
	3.52	124
	1.76	127
	0.88	130
	0.44	133
	0.22	136
	0.11	139

Table A-2. TLVs for Continuous Exposure to Airborne Ultrasound. From ACGIH®, *2008 TLVs® and BEIs®* (p. 124), Ohio: ACGIH. Copyright 2008 by American Conference of Governmental Industrial Hygienists. Reprinted with permission.

	One-third Octave-Band Level Measured in Air; Head in Air (dB)	
Mid-Frequency of Third-Octave Band (kHz)	Ceiling Values	8-Hour TWA
10	105	88
12.5	105	89
16	105	92
20	105	94
25	110	-
31.5	115	-
40	115	-
50	115	-
63	115	-
80	115	-
100	115	-

Table A-3. OSHA PELs for noise (U.S. DOL, 2008).

Duration (hours)	Sound Level (dBA, slow response)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 (or less)	115

Table A-4. OSHA allowable exposure times (U.S. DOL, 2007).

A-weighted Sound Level	Reference Duration (hour)	A-weighted Sound Level	Reference Duration (hour)
80	32	106	0.87
81	27.9	107	0.76
82	24.3	108	0.66
83	21.1	109	0.57
84	18.4	110	0.5
85	16	111	0.44
86	13.9	112	0.38
87	12.1	113	0.33
88	10.6	114	0.29
89	9.2	115	0.25
90	8	116	0.22
91	7	117	0.19
92	6.1	118	0.16
93	5.3	119	0.14
94	4.6	120	0.125
95	4	121	0.11
96	3.5	122	0.095
97	3	123	0.082
98	2.6	124	0.072
99	2.3	125	0.063
100	2	126	0.054
101	1.7	127	0.047
102	1.5	128	0.041
103	1.3	129	0.036
104	1.1	130	0.031
105	1		

Appendix B: Compiled Data

Table B-1. Noise dosimeter parameters using ACGIH guidelines for 26-Jun-08; 27-Jun-08; 30-Jun-08

Category	**Setting**
Response	Fast
Frequency Weighting	A
Threshold	40 dB
Exchange Rate	3 dB
Criterion Level	85 dBA

Table B-2. Noise dosimeter parameters using OSHA guidelines for 19-Aug; 20-Aug; 28-Aug; 19-Sep; 2-Oct

Category	**Setting**
Response	Slow
Frequency Weighting	A
Threshold	80 dB
Exchange Rate	5 dB
Criterion Level	90 dBA

Table B-3. Quest and Larson Davis Real-time analyzer parameters.

Category	**Setting**
Response	Fast
Frequency Weighting	Flat
Threshold	
Exchange Rate	3 dB
Criterion Level	

Table B-4. Calibration data for Real-Time Analyzers.

Sample Date	RTA	Pre-Calibration	Post-Calibration
26-Jun-08			
	Quest	114.0	114.0
	Larson Davis	114.0	114.0
27-Jun-08			
	Quest	114.0	114.0
	Larson Davis	114.0	114.0
19-Aug-08			
	Larson Davis	113.9	114.0
20-Aug-08			
	Larson Davis	114.0	114.1
28-Aug-08			
	Larson Davis	114.1	114.1
19-Sep-08			
	Larson Davis	114.1	114.2
2-Oct-08			
	Larson Davis	114.0	114.3

Table B-5. Calibration data for noise dosimeters.

Sample Date	Instrument	Pre-Calibration	Post-Calibration
26-Jun-08			
	1-8	114.0	113.8
	2-35008	114.0	114.2
	1-9	114.0	113.8
	2-13	114.0	114.2
	1-10	114.0	113.7
	2-10	114.0	114.0
27-Jun-08			
	1-8	114.0	114.2
	2-35008	114.0	114.0
	1-9	114.0	114.2
	2-13	114.0	114.0
	1-10	114.0	114.1
	2-10	114.0	114.0
30-Jun-08			
	1-8	114.0	114.1
	2-35008	114.0	114.0
	1-9	114.0	114.0
	2-13	114.0	113.8
	1-10	114.0	114.0
	2-10	114.0	114.0
19-Aug-08			
	1-9	113.9	114.0
	2-13	114.0	114.0
20-Aug-08			
	1-9	114.0	114.1
	2-13	114.0	114.0
28-Aug-08			
	1-9	114.0	114.0
	2-13	114.1	114.1
19-Sep-08			
	1-9	114.1	113.9
	2-13	114.0	113.9
2-Oct-08			
	1-9	114.0	114.2
	2-13	114.1	114.0

Appendix C: Larson Davis Sound-Pressure Levels per Workshift

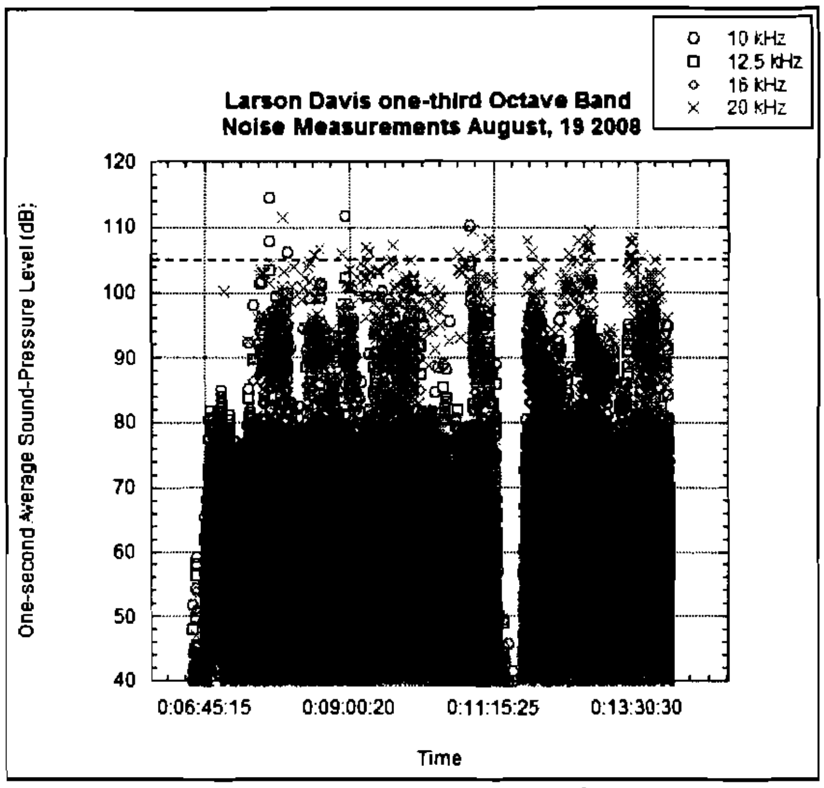

Figure C-1. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

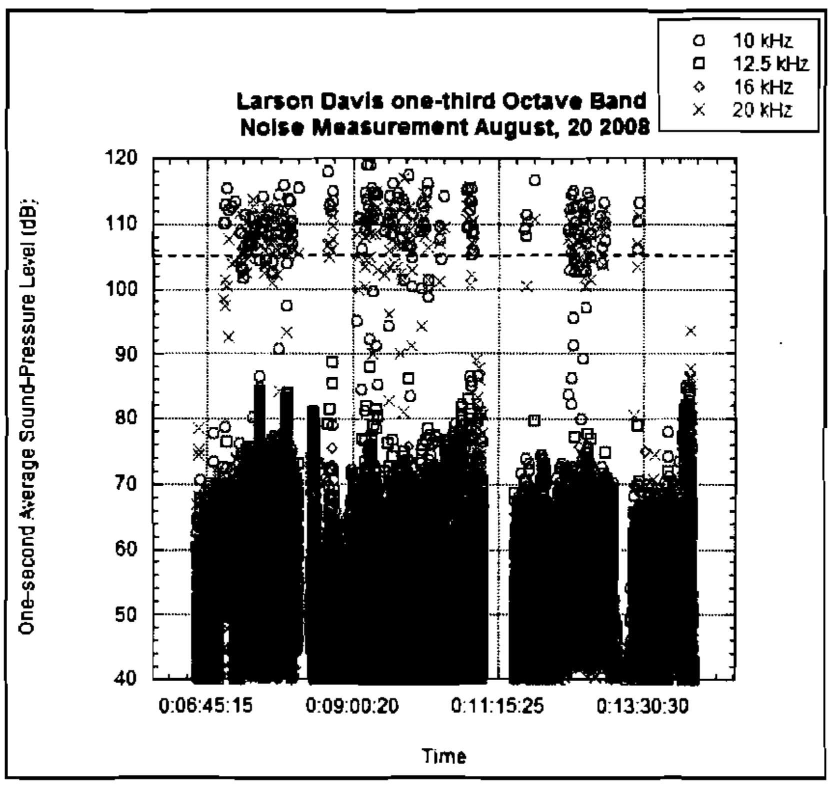

Figure C-2. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

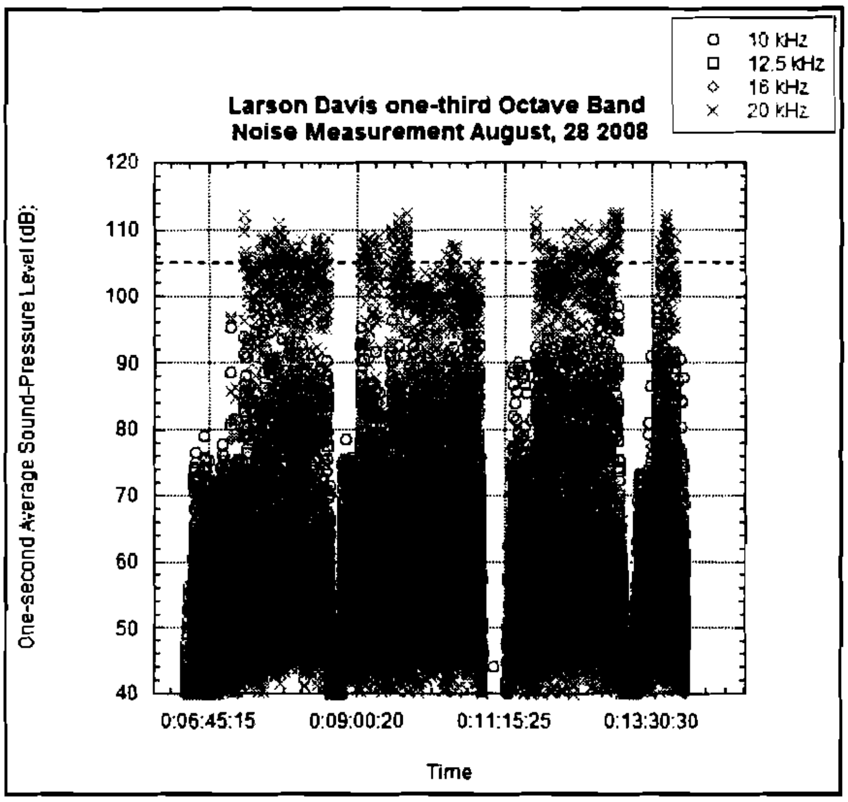

Figure C-3. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

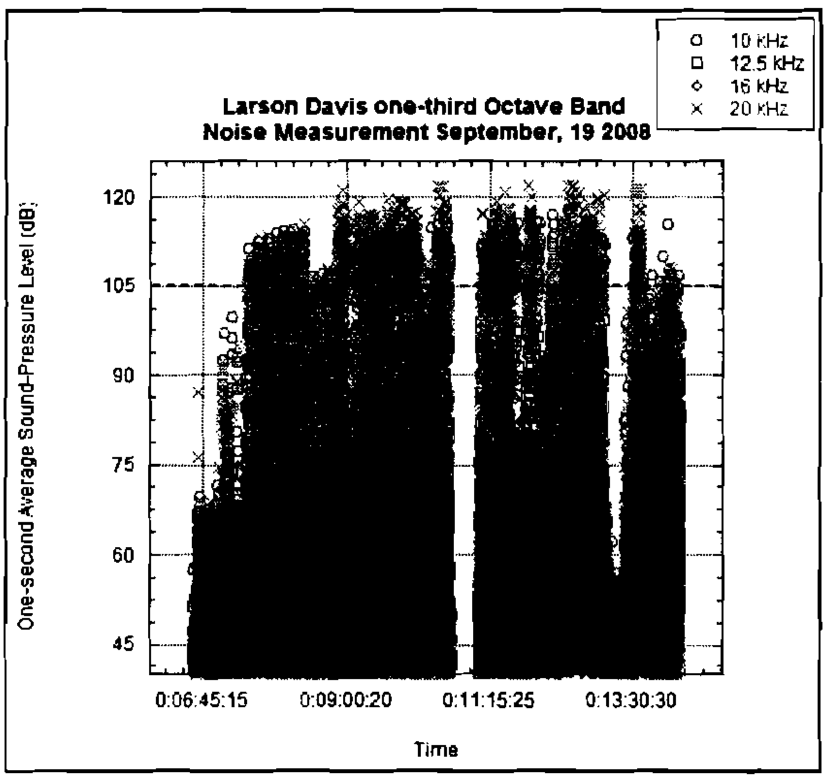

Figure C-4. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

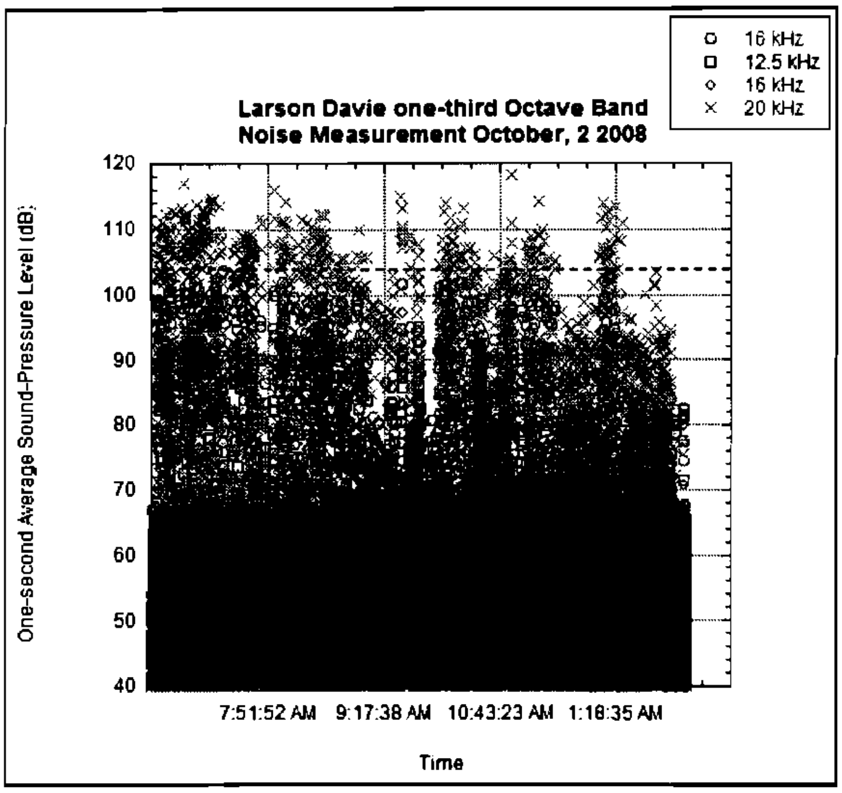

Figure C-5. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

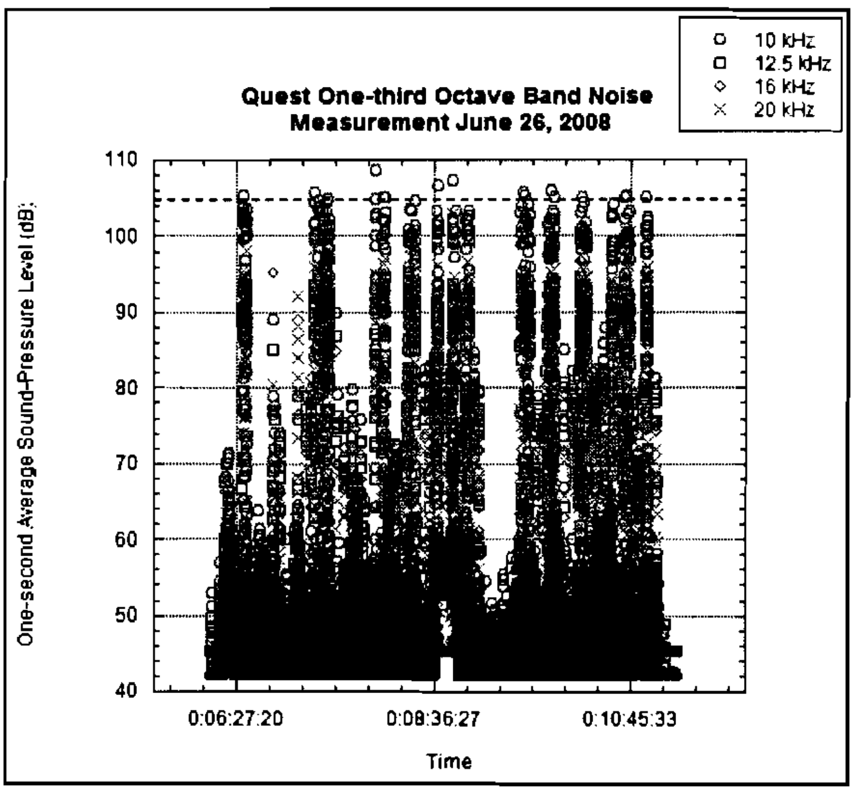

Figure C-6. Noise pattern observed for each frequency band, dashed line represents SPL exceeding ACGIH ceiling limit of 105 dB.

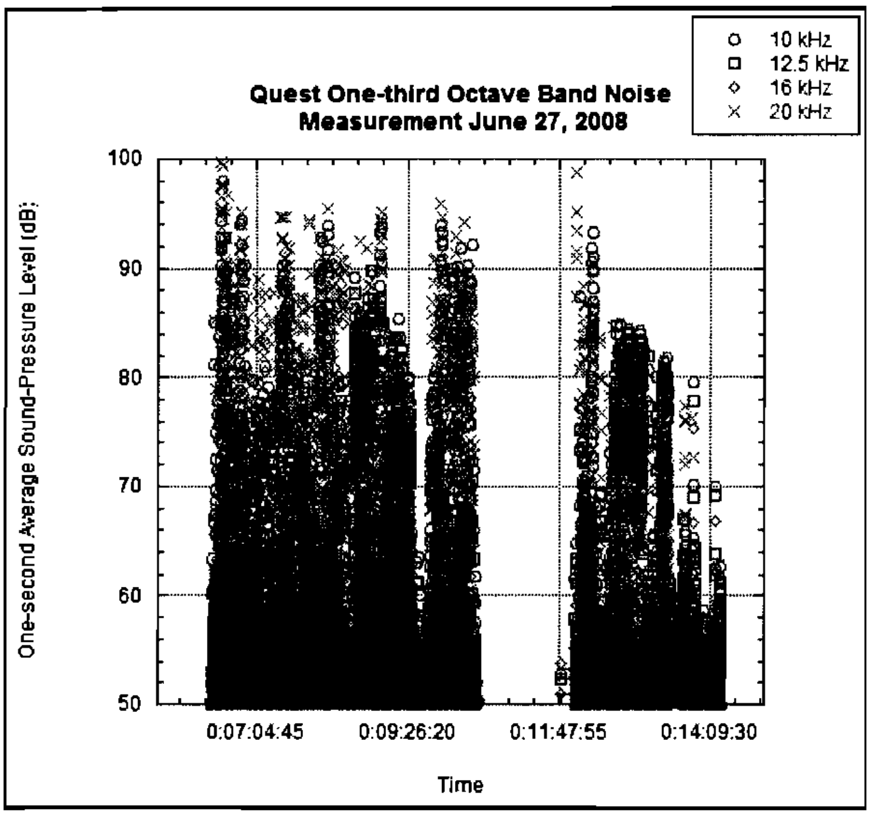

Figure C-7. Noise pattern observed for each frequency band. There were no values exceeding the ACGIH ceiling value of 105 dB.

Appendix D: Correlation Graphs of Type 1 and Type 2 Dosimeters

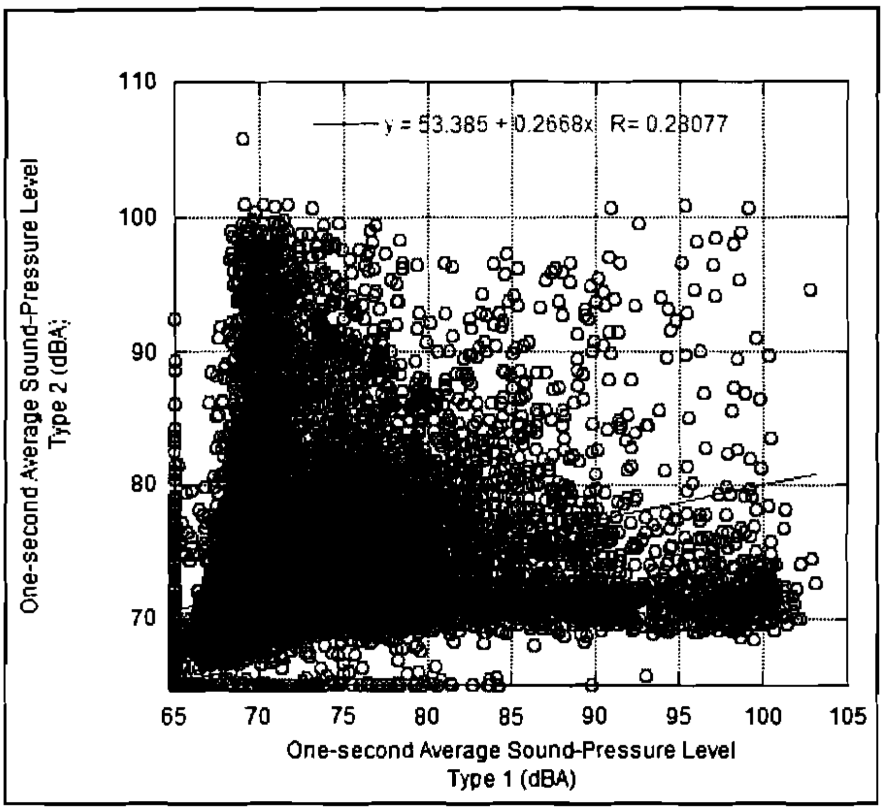

Figure D-1. Correlation of Set A dosimeter SPL measurements, June 26, 2008.

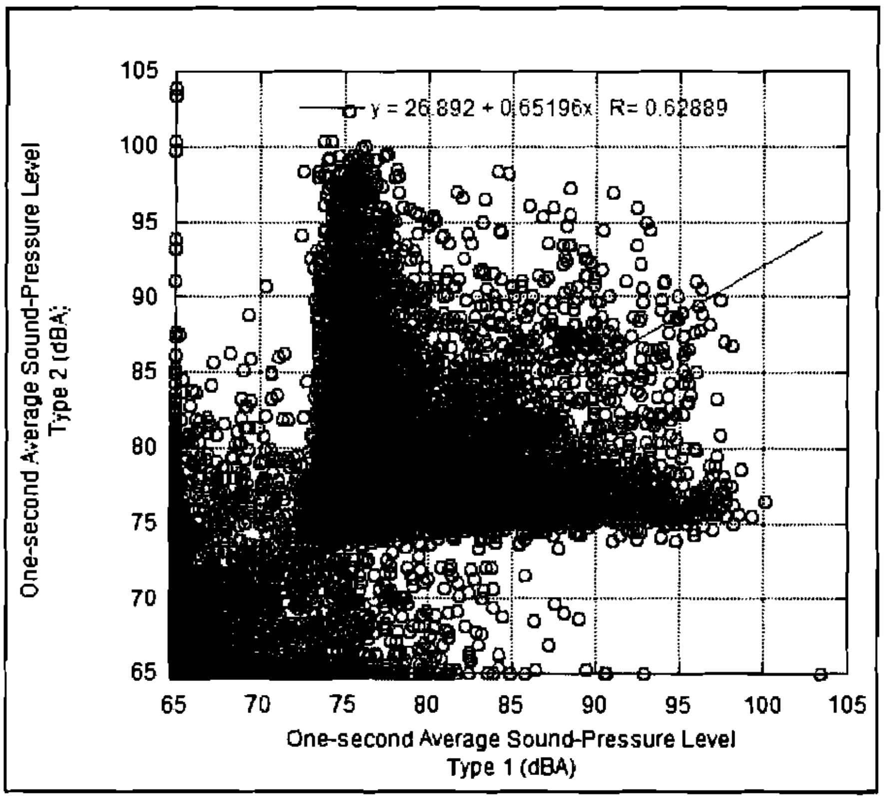

Figure D-2. Correlation of Set B dosimeter SPL measurements, June 26, 2008.

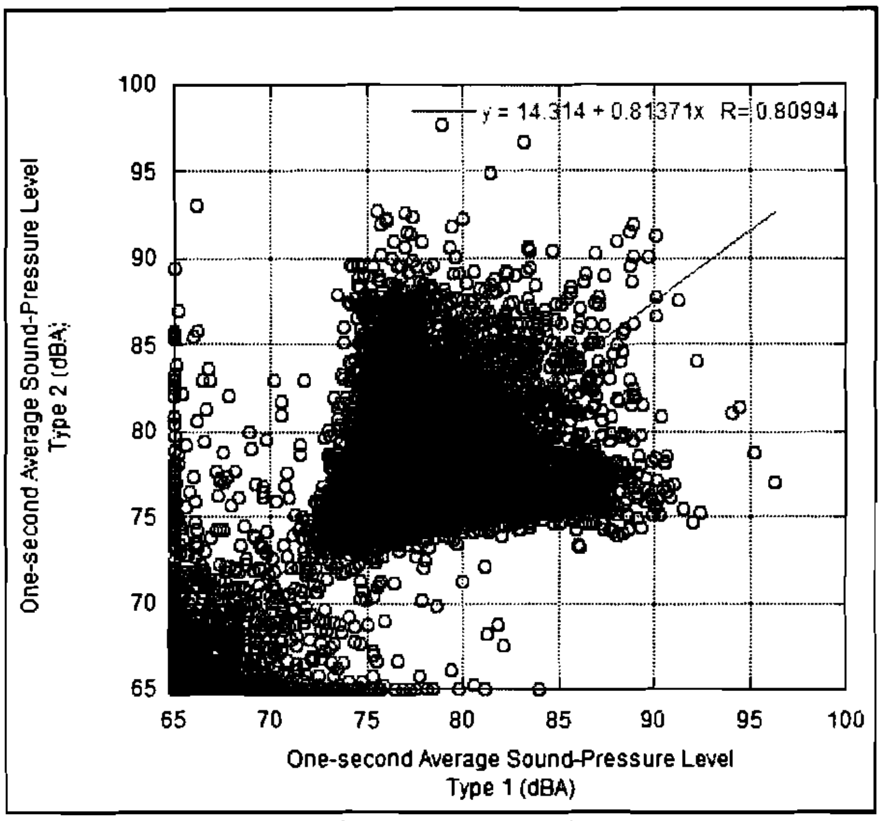

Figure D-3. Correlation of Set C dosimeter SPL measurements, June 26, 2008.

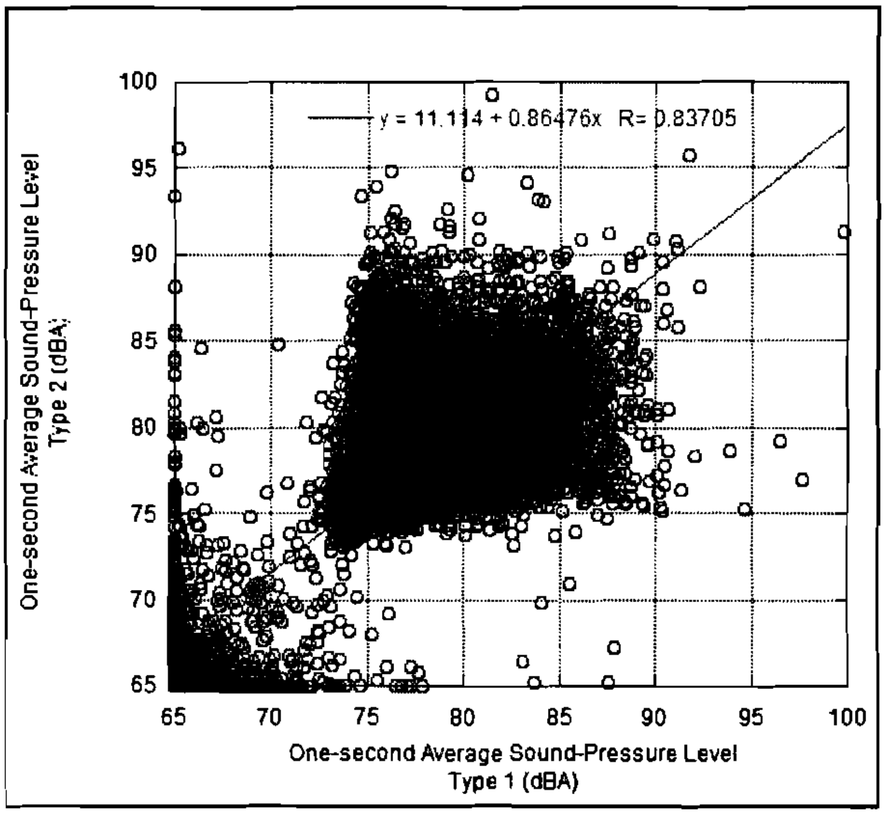

Figure D-4. Correlation of Set A dosimeter SPL measurements, June 27, 2008.

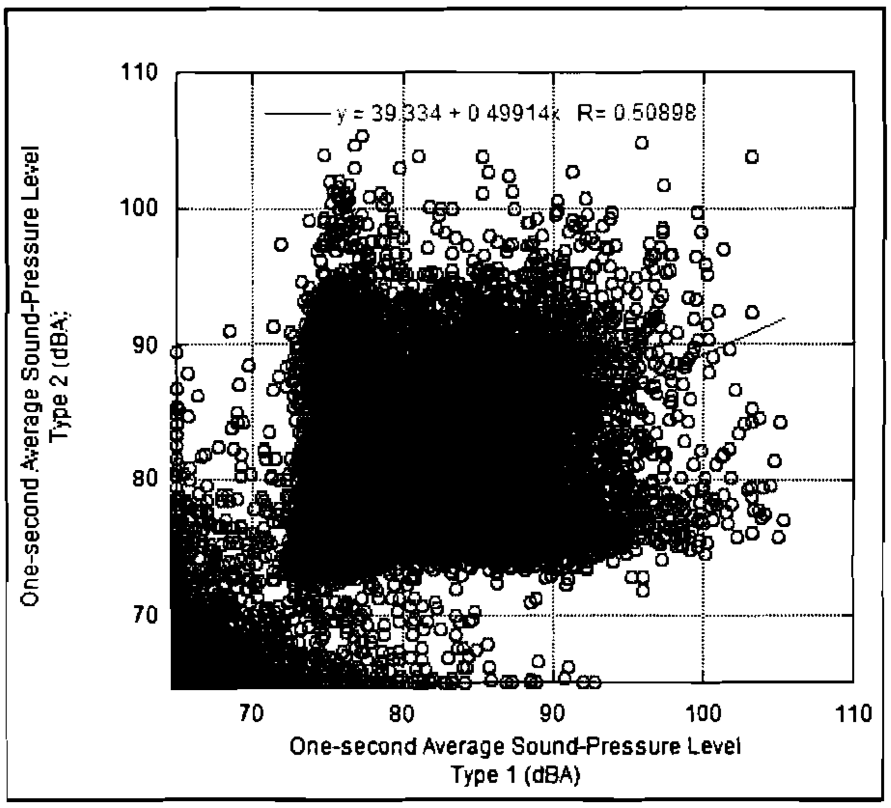

Figure D-5. Correlation of Set B dosimeter SPL measurements, June 27, 2008.

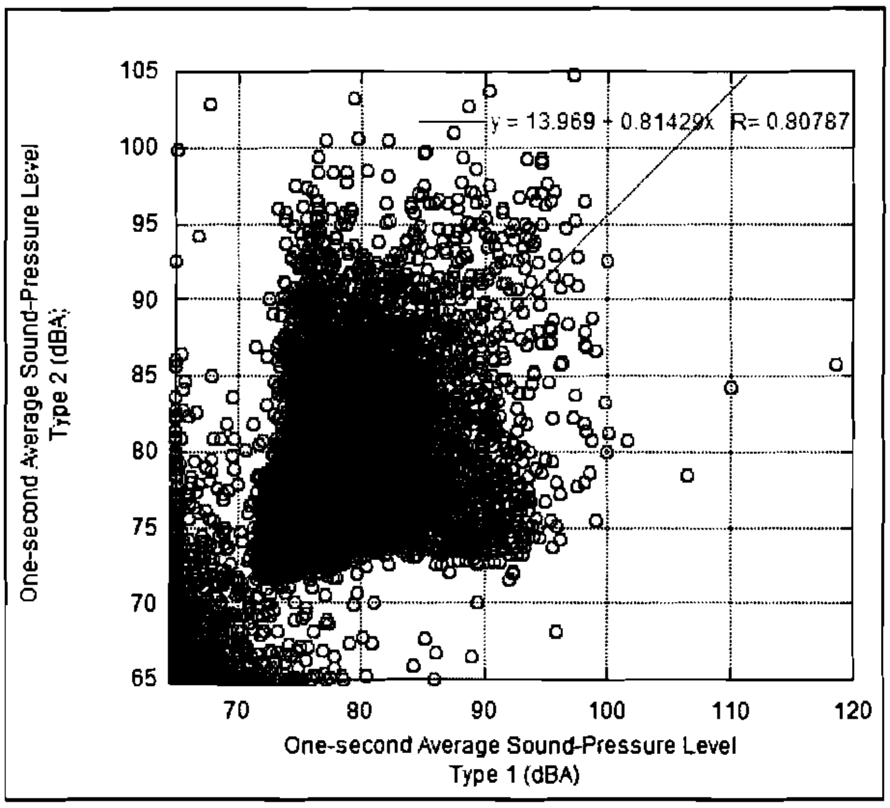

Figure D-6. Correlation of Set C dosimeter SPL measurements, June 27, 2008.

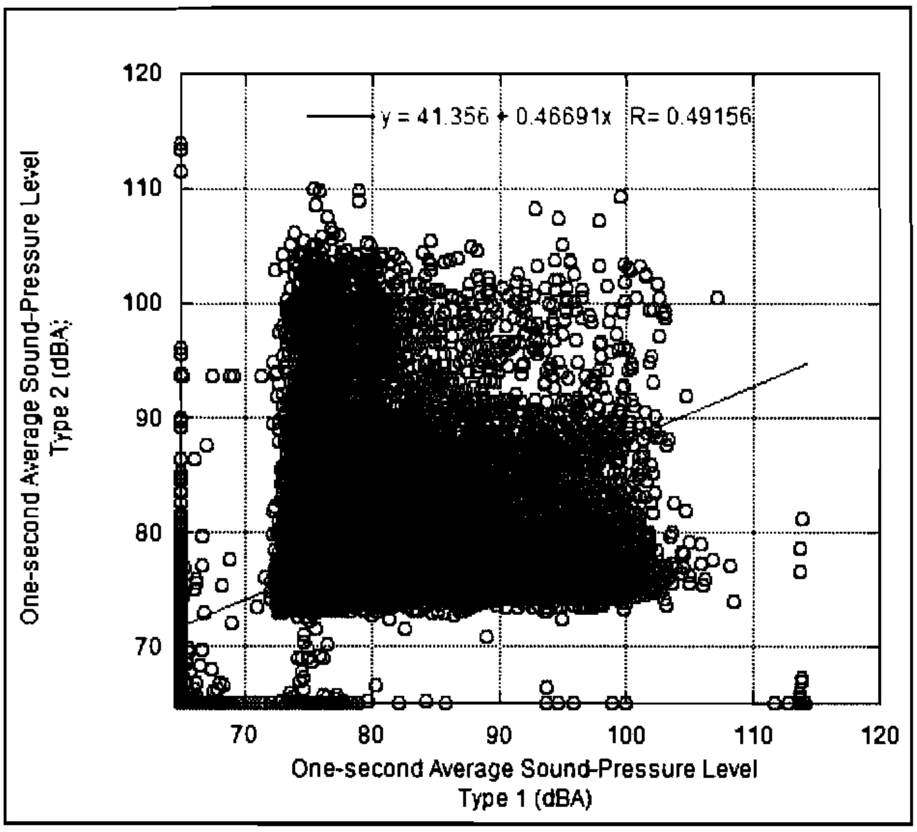

Figure D-7. Correlation of Set A dosimeter SPL measurements, June 30, 2008.

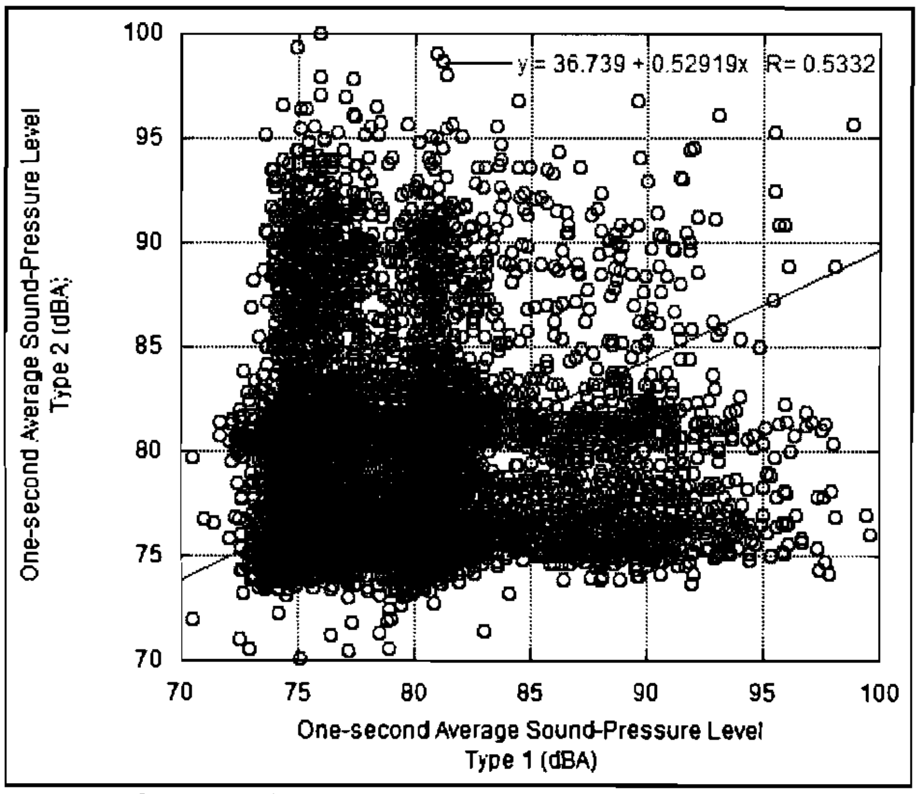

Figure D-8. Correlation of Set B dosimeter SPL measurements, June 30, 2008.

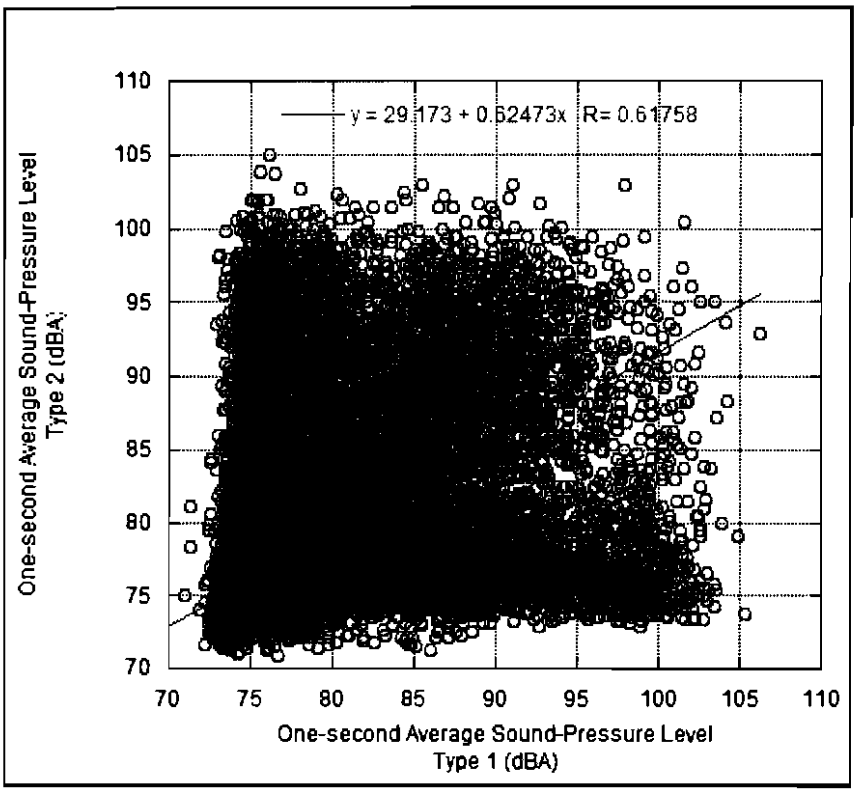

Figure D-9. Correlation of Set C dosimeter SPL measurements, June 30, 2008.

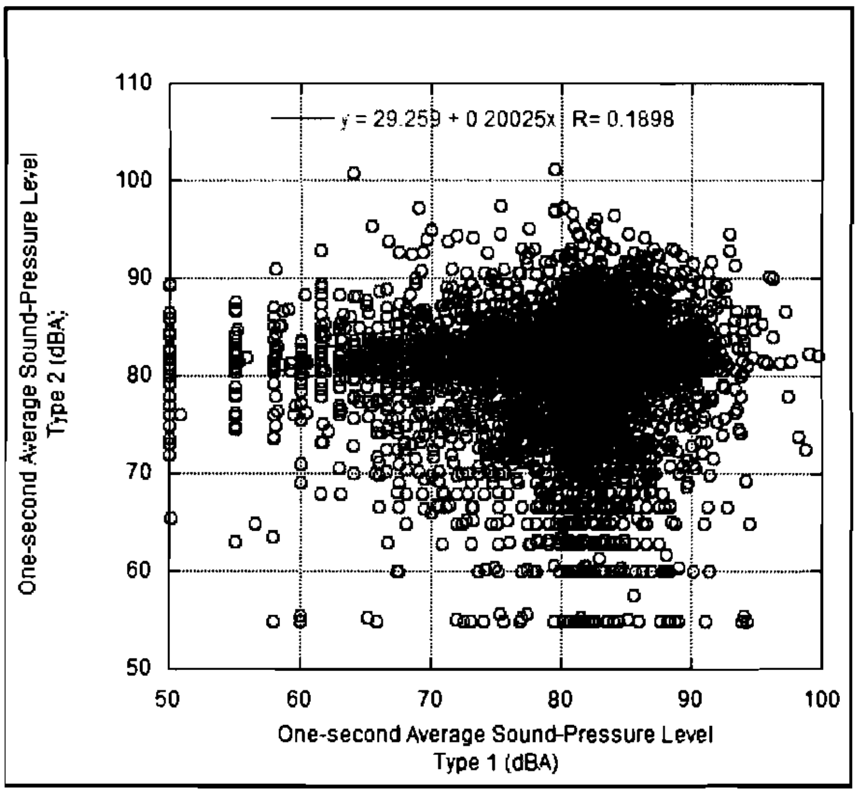

Figure D-10. Correlation of Set B dosimeter SPL measurements, August 19, 2008.

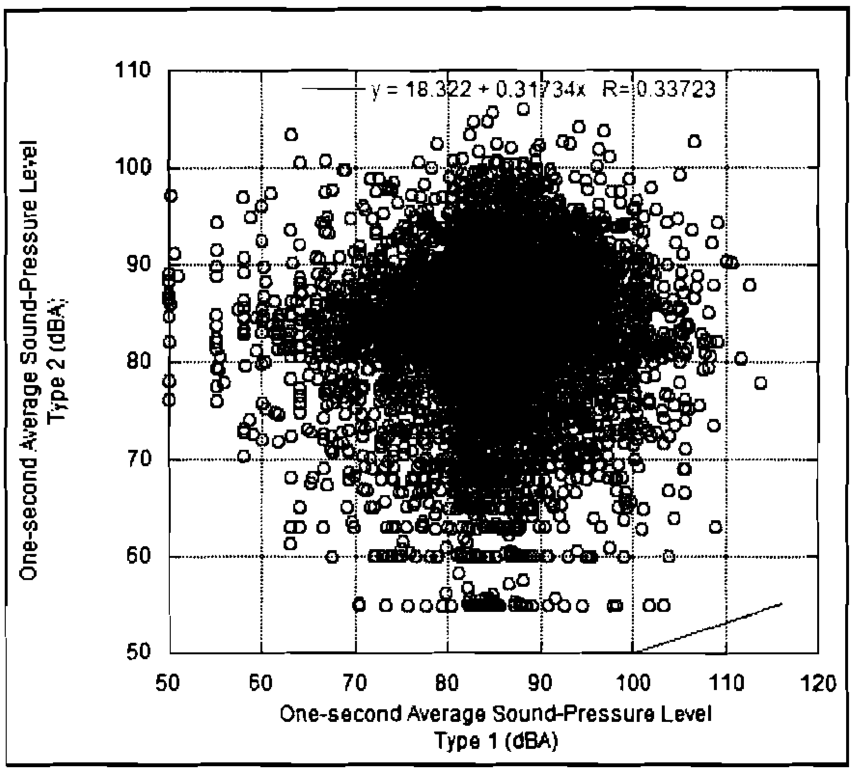

Figure D-11. Correlation of Set B dosimeter SPL measurements, August 20, 2008.

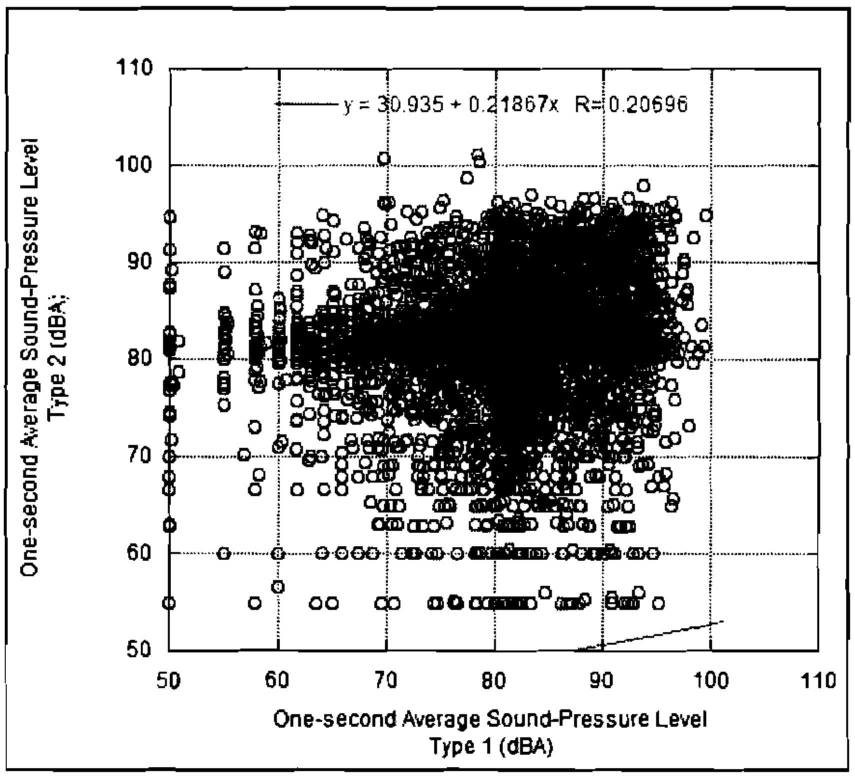

Figure D-12. Correlation of Set B dosimeter SPL measurements, August 28, 2008.

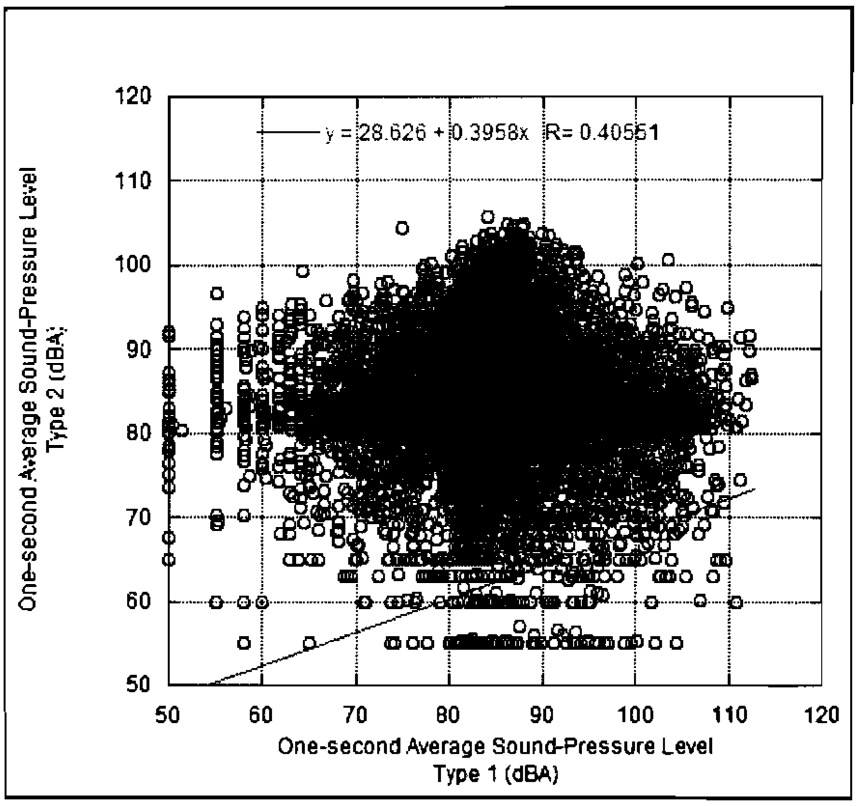

Figure D-13. Correlation of Set B dosimeter SPL measurements, September 19, 2008.

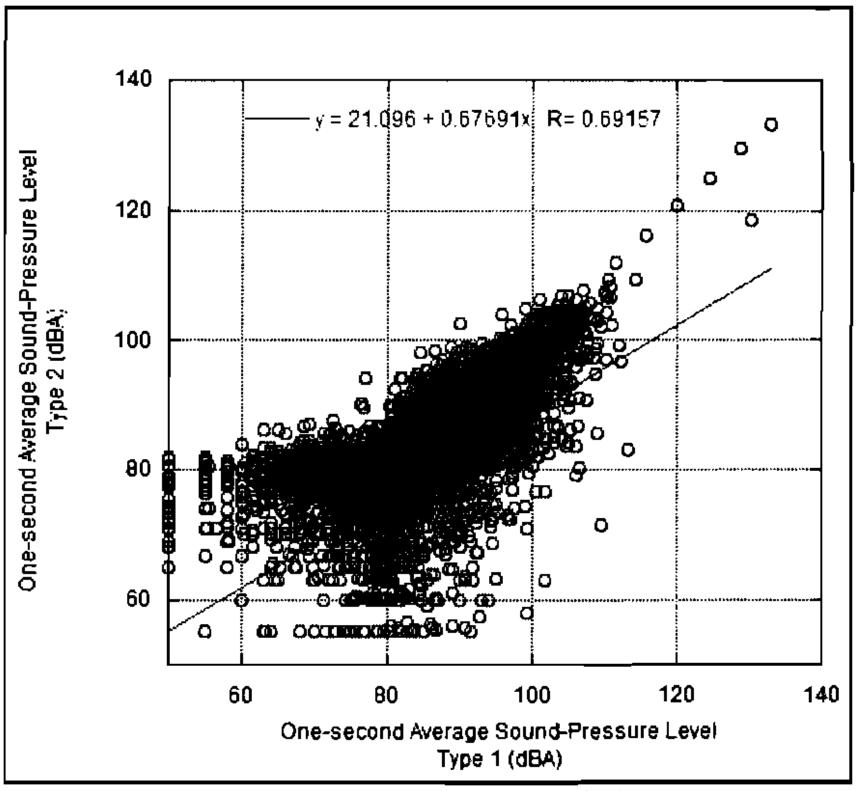

Figure D-14. Correlation of Set B dosimeter SPL measurements, October 2, 2008.

Appendix E: Pictures of Welded Components

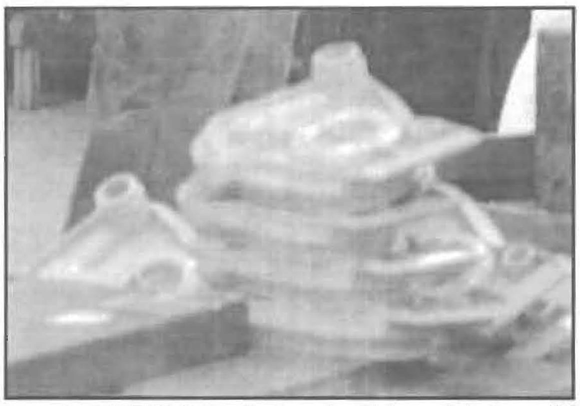

Figure E-1. Cover manifold (plastic to plastic) welded on 19 August, 2008.

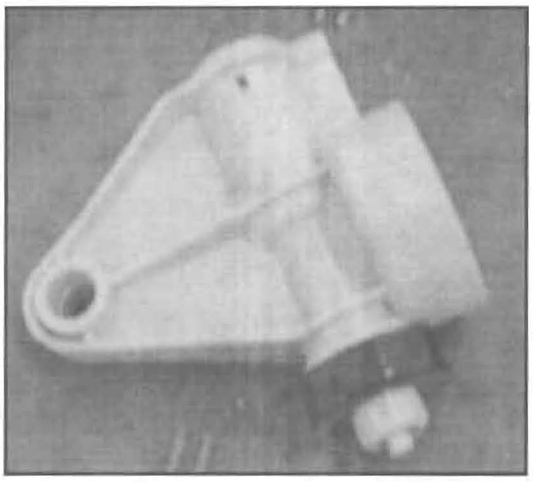

Figure E-2. Dispensing head (plastic to plastic) welded on 20 August, 2008.

Figure E-3. Port housing cover (metal to plastic) welded on 28 August, 2008.

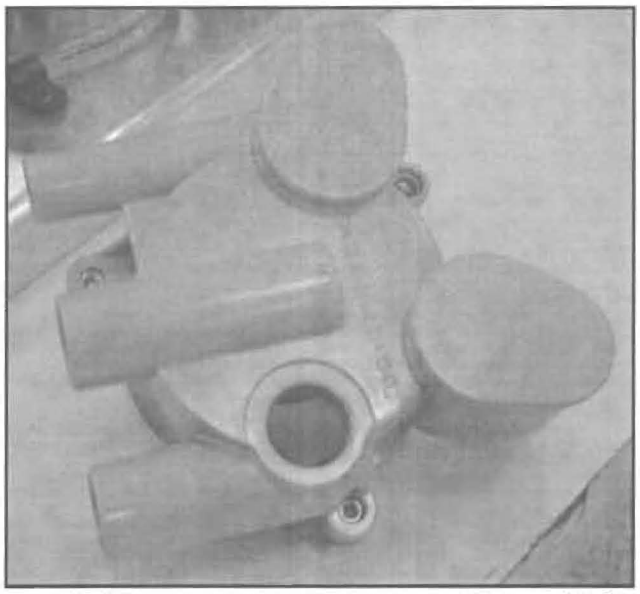

Figure E-4. Base exhalation (plastic on plastic) welded on 19 September, 2008.

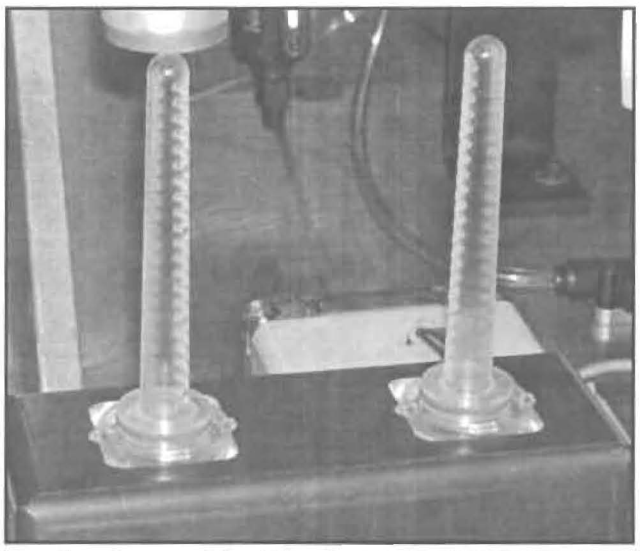

Figure E-5. Filter head assembly (plastic on plastic) welded 2 October, 2008.

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Defining the Science of Occupational and Environmental Health®

November 20, 2008

Kaprice J. Knaup
Risk Control Graduate Student
University of Wisconsin-Stout
knaupk@uwstout.edu

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Rita L. Williams

Rita L. Williams
Communications Manager

Appendix G: ACGIH Statement of Position

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Defining the Science of Occupational and Environmental Health®

ACGIH® Statement of Position Regarding the TLVs® and BEIs®

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Each year ACGIH® publishes its TLVs® and BEIs® in a book. In the introduction to the book, ACGIH® states that the TLVs® and BEIs® are guidelines to be used by professionals trained in the practice of industrial hygiene. The TLVs® and BEIs® are not designed to be used as standards. Nevertheless, ACGIH® is aware that in certain instances the TLVs® and the BEIs® are used as standards by national, state, or local governments.

Governmental bodies establish public health standards based on statutory and legal frameworks that include definitions and criteria concerning the approach to be used in assessing and managing risk. In most instances, governmental bodies that set workplace health and safety standards are required to evaluate health effects, economic and technical feasibility, and the availability of acceptable methods to determine compliance.

ACGIH® TLVs® and BEIs® are not consensus standards. Voluntary consensus standards are developed or adopted by voluntary consensus standards bodies. The consensus standards process involves canvassing the opinions, views and positions of all interested parties and then developing a consensus position that is acceptable to these parties. While the process used to develop a TLV® or BEI® includes public notice and requests for all available and relevant scientific data, the TLV® or BEI® does not represent a consensus position that addresses all issues raised by all interested parties (e.g., issues of technical or economic feasibility). The TLVs® and BEIs® represent a scientific opinion based on a review of existing peer-reviewed scientific literature by committees of experts in public health and related sciences.

ACGIH® TLVs® and BEIs® are health-based values. ACGIH® TLVs® and BEIs® are established by committees that review existing published and peer-reviewed literature in various scientific disciplines (e.g., industrial hygiene, toxicology, occupational medicine, and epidemiology). Based on the available information, ACGIH® formulates a conclusion on the level of exposure that the typical worker can experience without adverse health effects. The TLVs® and BEIs® represent conditions under which ACGIH® believes that nearly all workers may be repeatedly exposed without adverse health effects. They are not fine lines between safe and dangerous exposures, nor are they a relative index of toxicology. The TLVs® and BEIs® are not quantitative estimates of risk at different exposure levels or by different routes of exposure.

Since ACGIH® TLVs® and BEIs® are based solely on health factors, there is no consideration given to economic or technical feasibility. Regulatory agencies should not assume that it is economically or technically feasible for an industry or employer to meet TLVs® or BEIs®. Similarly, although there are usually valid methods to measure workplace exposures at TLVs® and BEIs®, there can be instances where such reliable test methods have not yet been validated. Obviously, such a situation can create major enforcement difficulties if a TLV® or BEI® was adopted as a standard.

ACGIH® does not believe that TLVs® and BEIs® should be adopted as standards without full compliance with applicable regulatory procedures including an analysis of other factors necessary to make appropriate risk management decisions. However, ACGIH® does believe that regulatory bodies should consider TLVs® or BEIs® as valuable input into the risk characterization process (hazard identification, dose-response relationships, and exposure assessment). Regulatory bodies should view TLVs® and BEIs® as an expression of scientific opinion.

ACGIH® is proud of the scientists and the many members who volunteer their time to work on the TLV® and BEI® Committees. These experts develop written *Documentation* that include an expression of scientific opinion and a description of the basis, rationale, and limitations of the conclusions reached by ACGIH®. The *Documentation* provides a comprehensive list and analysis of all the major published peer-reviewed studies that ACGIH® relied upon in formulating its scientific opinion. Regulatory agencies dealing with hazards addressed by a TLV® or BEI® should obtain a copy of the full written *Documentation* for the TLV® or BEI®. Any use of a TLV® or BEI® in a regulatory context should include a careful evaluation of the information in the written *Documentation* and consideration of all other factors as required by the statutes which govern the regulatory process of the governmental body involved.

- *ACGIH® is a not-for-profit scientific association.*
- *ACGIH® proposes guidelines known as TLVs® and BEIs® for use by industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace.*
- *ACGIH® is not a standards setting body.*
- *Regulatory bodies should view TLVs® and BEIs® as an expression of scientific opinion.*
- *TLVs® and BEIs® are not consensus standards.*
- *ACGIH® TLVs® and BEIs® are based solely on health factors; there is no consideration given to economic or technical feasibility. Regulatory agencies should not assume that it is economically or technically feasible to meet established TLVs® or BEIs®.*
- *ACGIH® believes that TLVs® and BEIs® should NOT be adopted as standards without an analysis of other factors necessary to make appropriate risk management decisions.*
- *TLVs® and BEIs® can provide valuable input into the risk characterization process. Regulatory agencies dealing with hazards addressed by a TLV® or BEI® should review the full written Documentation for the numerical TLV® or BEI®.*

ACGIH® is publishing this Statement in order to assist ACGIH® members, government regulators, and industry groups in understanding the basis and limitations of the TLVs® and BEIs® when used in a regulatory context. This Statement was adopted by the ACGIH® Board of Directors on March 1, 2002

Appendix H: American Industrial Hygiene Association Copyright Permission

AIHA
Protecting Worker Health

November 21, 2008

Kaprice J. Knaup
Risk Control Graduate Student
University of Wisconsin–Stout

Dear Kaprice,

This letter is in response to your request to use Figure 4.1 (cross-sectional view of the human ear) from *The Noise Manual,* Revised 5th edition in your dissertation, "Determining the Efficacy of Various Noise Meters to Detect Ultrasound at Company XYZ."

AIHA grants this request providing the figure is not modified in any way. Please also make sure to provide the following credit line with the information as it is used: "Used with permission of the American Industrial Hygiene Association (2008)."

Thank you for your interest and if you have any further questions, please don't hesitate to give me a call.

Sincerely,

Katie Robert

Katie Robert
Manager, Product Development
American Industrial Hygiene Association

Appendix I: Industrial Acoustics Company Copyright Permission

TO: KAPRICE KNAUP

FROM: MAUREEN GIBSON

SUBJECT: PREMISSION OF USE COPYRIGHT MATERIAL

DATE: NOVEMBER 17, 2008

Dear Kaprice,

We are pleased to provide you permission to use the drawing on page C-3 in Industrial Acoustics Company's *Noise Control Reference Handbook (1989).*

Thank you for including IAC in your dissertation.

Sincerely,

Maureen Gibson
Assistant to the President & General Manager
Industrial Acoustics Company, Inc.
mgibson@industrialacoustics.com
(718) 430-4524

Appendix J: Quest Technologies, Inc. Copyright Permission

From: Jim Banach [JBanach@quest-technologies.com] Sent: Mon 12/8/2008 2:22 PM
To: Knaup, Kaprice J
Cc:
Subject: Authorization to reproduce graphics from the Quest Product Manual
Attachments:

To: Kaprice Knaup

From: Jim Banach
Executive Vice President
Quest Technologies, a 3M company

Regarding your request to reproduce drawings from a Quest product manual for use in your dissertation, please accept this as such approval. Please give appropriate reference and credit to the applicable Quest product manual.

Appendix K: UW-Stout Protection of Human Subjects in Research Form

University of Wisconsin Stout
Protection of Human Subjects in Research Form

Data collection analysis cannot begin until there has been IRB approval of this project

Directions:

- **Individuals who have completed the UW-Stout Human Subjects Training and can prove certification are eligible to file this form.**
- **This form must be filed and approved <u>prior</u> to any student (undergraduate or graduate), faculty, or staff conducting research.**
- **Complete this form on-line and print. <u>Handwritten forms will not be accepted</u>.** ***For your benefit, save your completed form in case it needs to be revised and resubmitted.***
- **Send or take the completed form, with required signatures and required materials attached, to Research Services, 152 Voc. Rehab. Building.**
- **This is a professional document; please check spelling, grammar and punctuation.**

Research is defined as a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge.

A human subject is defined as a living individual about whom an investigator obtains either 1) data through intervention or interaction with the individual; or 2) identifiable private information.

Investigator(s):
Name: Kaprice J. Knaup ID: Daytime Phone #
e-mail address: knaupk@uwstout.edu Signature: ______________________

Name: ID: Daytime Phone #
e-mail address: Signature: ______________________

Name: ID: Daytime Phone #
e-mail address: Signature: ______________________

For students:
Research Advisor's Name: Eugene Ruegner Department: Chemistry
Signature: ______________________ Date of Approval: __________
Research Advisor: Have you completed UW-Stout's Human Subjects Training? Yes ☒ No☐.
Reminder: You must have completed the new training after January 2, 2007.

Project Title: Effectiveness of Containment Devices to Reduce Employee Exposure to Ultrasonic Sound at Company XYZ

Sponsor (Funding agency, if applicable):
Is this project being supported by Federal funding? Yes ☒ No ☐

You must answer all of the following questions completely and attach all required forms.

1. Describe the proposed research activity stating the objectives, significance, and detailed methodology (approximately 250-500 words, descriptions are to be written in future tense).

Objectives:

1) To determine the range of sound-pressure level exposures experienced by workers using ultrasonic equipment as measured by Type 1 and Type 2 noise dosimeters.

2) To compare the sound-pressure level measurements from the Type 1 and Type 2 noise dosimeters to current OSHA regulations and ACGIH guidelines.

3) To determine if the use of sound enclosures is effective in reducing ultrasonic noise levels during the operation of ultrasonic welders.

4) To determine if the effect of ultrasonic sound is dependent on the type of components being welded.

5) To determine if the operators of ultrasonic welders at Company XYZ have experienced hearing loss or adverse health effects due to airborne ultrasonic noise.

Significance:

This study provided information on employee noise exposure during the use of ultrasonic welders, assessed the adequacy for the current monitoring protocol for evaluating the work environment, and explored the use of sound enclosures to minimize worker exposure to ultrasonic noise.

Detailed Methodology:

1. Place Type 1 and Type 2 noise dosimeters microphones adjacent to each other and meausre and log, at one-second intervals, the personal full-shift exposures of employees during manufacturing using an ultrasonic welder.
2. Use a Real-time Analyzer to measure and log, at one-second intervals, the third-octave sound pressure levels at the dosimter microphone position.
3. Collect 5 full shift sets of data
4. After the sound containment device has been installed on the ultrasonic welders, repeat steps 1 thru 3.
5. Compare the Type 1 and Type 2 sound intensities using Student's t-Test for paired data.
6. Compute the average sound-pressure level, Leq, experienced by each employee for each dosimeter. Present the range of exposures using descriptive statistics.
7. Evaluate the employee exposures with respect ot the OSHA Permissible Exposure Limits regulations and the ACGIH Threshold Limit Value recommendations.

2. **Is this research?**
   (a) Is your activity intended for public dissemination? Yes ☒ No ☐
   (b) Can it reasonably be generalized beyond the research sample? Yes ☒ No ☐

If you answered no to these two questions, do not continue with this form. Stop here and submit form.

3. Does your research involve human subjects or official records about human subjects? Yes ☒ No ☐

If yes, continue with this form. If no, stop here and submit form.

4. Are you requesting exemption from IRB review in one of the federally approved categories? If yes, please reference OHRP website http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm#46.101 and select category that applies and continue with form. **If no, continue with Question #6 regarding Human Subjects Training.**

   ☐ (1) Is your research conducted in established or commonly accepted educational settings, involving normal education practices?
   ☐ (2/3) Is your research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior, AND identifying information will not be collected?
   ☐ (4) Is your research involving the collection or study of existing data, documents, records, or pathological or diagnostic specimens?
   ☐ (5) Is your research involving studying, evaluating, or examining public benefit or service programs AND conducted through a federal agency?
   ☐ (6) Is your research involving taste and food quality evaluation or consumer acceptance studies?

5. Human subjects training must be completed prior to filing this form. Have you completed UW-Stout's Human Subjects Training (http://www.uwstout.edu/rs/hstraining/index.htm)? Yes ☒ No ☐

6. Please note that research cannot begin until this project has been approved by the IRB. When is the data collection for the research *intended* to begin and end? **August 20th/08** to **October/08** (enter month/year)

7. Can the subjects be identified directly or through any type of identifiers? Yes ☒ No ☐ If yes, please explain.
   The results of this study are part of the employee's OSHA records with the company.

8. Special precautions must be included in your research procedures if any of these special populations or research areas are included.

Are any of the subjects:
(a) minors (under 18 years of age)? Yes ☐ No ☒
(consent from parent & subject required)
(b) legally incompetent? Yes ☐ No ☒
(c) prisoners? Yes ☐ No ☒
(d) pregnant women, if affected by the research? Yes ☐ No ☒
(e) institutionalized? Yes ☐ No ☒
(f) mentally incapacitated? Yes ☐ No ☒

Does the research deal with questions concerning:
(a) sexual behaviors? Yes ☐ No ☒
(b) drug use? Yes ☐ No ☒
(c) illegal conduct? Yes ☐ No ☒
(d) use of alcohol? Yes ☐ No ☒

9. Voluntary participation/consent form:
Expected Number of Participants **This study is being conducted to ensure compliance with OSHA regulations. Participation is a condition of employment, and as such is not voluntary.**

Describe the method:
(a) for selecting subjects.
Whomever is operating the ultrasonic welder at the date and time I will be doing noise monitoring

(b) for assuring that their participation is voluntary. If subjects are children and they are capable of assent, they must give their permission, along with that of their parent, guardian, or authorized representative. NOTE: A school district cannot give permission or consent on behalf of minor children

10. Procedures. Describe how subjects will be involved in detail.
The workers at Company XYZ will be wearing Type1 and Type2 noise dosimeters microphones for their full-shift.

If the study:
(a) involves false or misleading information to subjects, or
(b) withholds information such that their informed consent might be questioned, or
(c) uses procedures designed to modify the thinking, attitudes, feelings, or other aspects of the behavior of the subjects,
describe the rationale for that, how the human subjects will be protected and what debriefing procedures you will use.

11. <u>Special precautions must be included in your research procedures if you are doing an online survey.</u>
Are you doing an online survey? Yes ☐ No ☒
If yes, please answer the following questions. If no, please skip to the next question.

(a) Will your survey results be posted on a website that could be accessed by individuals other than the investigators?
Yes ☐ No ☐

(b) Does the URL for the survey include information that could identify individuals, such as a student ID?
Yes ☐ No ☐

(c) When you send out an email inviting subjects to complete the survey:
Will you place all of the email addresses in the "bcc" line? Yes ☐ No ☐
Will you have the "read receipt" function turned off? Yes ☐ No ☐

(d) If your survey contains questions where the subjects choose from a drop-down menu, do they have the option to choose "no response" or to leave the question blank?
Yes ☐ No ☐ No drop-down questions ☐

If in question #11, you answered "yes" to question (a) or (b), or if you answered "no" to question (c) or (d), please address your reason(s) when completing question #12.

12. Confidentiality: Describe the methods to be used to ensure the confidentiality of data obtained.
The identity of the employees will not be included in the thesis.

13. Risks: Describe the risks to the subjects and the precautions that will be taken to minimize them. (Risk includes any potential or actual physical risk of discomfort, harassment, invasion of privacy, risk of physical activity, risk to dignity and self-respect, and psychological, emotional, or behavioral risk.) Also, address any procedures that might be different from what is commonly established practice for research of this type.
This study is part of the employee's normal work environment and does not present any additional risks.

14. Benefits: Describe the benefits to subjects and/or society. (These will be balanced against risk.)
This study will provide information on employee noise exposure during the use of ultrasonic welders, assess the adequacy for the current monitoring protocol for evaluating the work environment, and explore the use of sound enclosures to minimize worker exposure to ultrasonic noise.

15. Attachments to this form: (NO ACTION WILL BE TAKEN WITHOUT THESE FORMS)

(a) Consent form(s). Form(s) should include explanation of procedures, risk, safeguards, freedom to withdraw, confidentiality, offer to answer inquiries, third party referral for concerns, and signature (only if the subjects can be identified by any means). If the survey is strictly anonymous, then a signature is not required). Sample consent forms can be found at http://www.uwstout.edu/rs/documents/cform.doc

(b) Questionnaire/Survey Instrument. The final version of the Questionnaire/Survey instrument must be attached. Also, if the survey is being conducted verbally, a copy of the introductory comments and survey questions being asked must be attached to this form. If your survey includes focus group questions, a complete list of the questions should be attached. For research using a published/purchased instrument, a photocopy of the complete survey will suffice.

(c) Printed copy of the UW-Stout Human Subjects Training Certification

The project or activity described above must adhere to the University's policies and institutional assurance with the U.S. Department of Health and Human Services regarding the use of human subjects. University review and approval is required. **REMINDER: You are in violation of UW-Stout, UW System, and federal government policies if you begin your study before IRB approval is obtained.**

Projects that are not completed within one year of the IRB approval date must be submitted again. Annual review and approval by the IRB is required. Projects that are determined to be exempt from IRB review hold exempt status for a period of 5 years, unless there are significant changes to the project.

Institutional Review Board Action:

______ Project is exempt from IRB review under category ____. Exemption holds for 5 years.

______ Project approved through expedited review.

______ Project approved through expedited review provided minor modifications are completed.

______ Project approved through the full board review process; date of meeting: ______________

______ Additional information is requested. Please see attached instructions and resubmit.

______ Project not approved at this time.

______ Project does not include human subjects.

______ Project is not defined as research.

Signature: ____

Institutional Review Board Chair or Designee Date

Appendix L: Branson 2000 d/aed Assembly System Brochure

BRANSON
2000 SERIES

Ultrasonic Assembly Systems

2000d/aed

- *Enhanced Performance*
- *Weld by Distance*
- *Amplitude Stepping*
- *Force Measurement*
- *Calibration*
- *Data Management*
- *Multiple Language Choices*

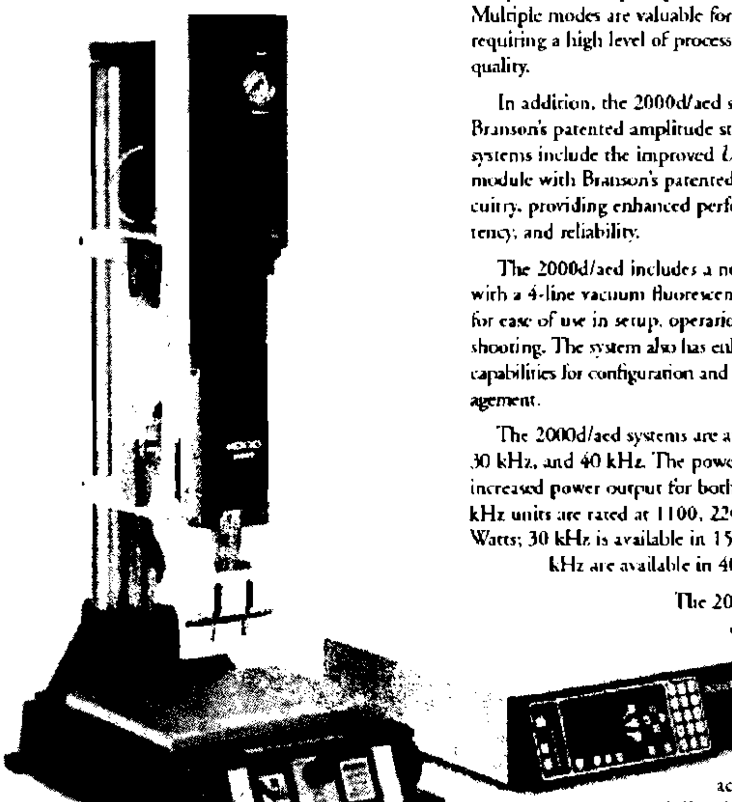
GENERAL DESCRIPTION

Branson introduces the 2000d/aed ultrasonic assembly systems, setting a new standard for users operating in the distance, time, energy, energy compensation, or peak power welding modes. Multiple modes are valuable for applications requiring a high level of process control and weld quality.

In addition, the 2000d/aed systems feature Branson's patented amplitude stepping. These systems include the improved *UPS* power supply module with Branson's patented closed loop circuitry, providing enhanced performance, consistency, and reliability.

The 2000d/aed includes a new user interface with a 4-line vacuum fluorescent display designed for ease of use in setup, operation, and troubleshooting. The system also has enhanced data capabilities for configuration and information management.

The 2000d/aed systems are available in 20 KHz, 30 kHz, and 40 kHz. The power supplies have increased power output for both frequencies: 20 kHz units are rated at 1100, 2200, and 3300 Watts; 30 kHz is available in 1500 Watts; and 40 kHz are available in 400 and 800 Watts.



The 2000d/aed system is designed for use in manual, semi-automated, or fully automated environments. The actuator may be mounted directly to a machine frame, with a fixed support on a column and hub, or as a stand-alone system on a base with ergonomic light-force palm button switches.

Applied Technologies Group

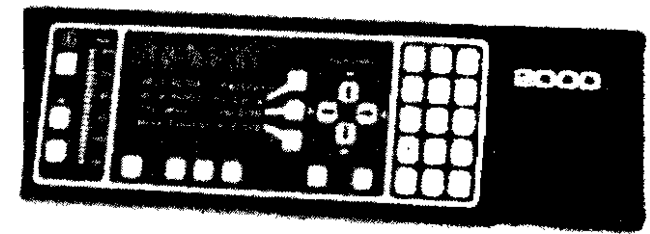
41 Eagle Road
Danbury, CT
06813-1961
(203) 796-0349
fax (203) 796-9838
email: info@bransonultrasonics.com

welding • staking • insertion • swaging • forming • spot welding • degating • cutting & sealing

KEY FEATURES

Note: items in blue are unique to the 2000d/aed systems.

User Interface/Process Controls



- **User interface featuring 4-line vacuum fluorescent (VF) display** makes setup, operation, diagnostics, and troubleshooting easier.
- **1 ms sampling rate of data** provides superior performance, consistency, and finer control.
- **Multiple welding modes** including distance (collapse and absolute), time, energy, peak power, and ground detect. Distance can be set in increments of 0.0001 inch. Energy is settable in increments of 0.1 joule. Peak power can be set in increments of 0.1%.
- **Force measurement capability** — set trigger force, and measure force for consistency and troubleshooting.
- **User calibratable force and pressure.**
- **Controllable velocity** provides readout and graphs of velocity for cycle monitoring and weld consistency.
- **Amplitude Stepping** — Branson's patented real-time process control provides increased strength, control of flash, reduction of particulate, and reduced residual stress.
- **Expanded process control limits**, including distance (absolute and collapse, and trigger range), energy compensation, provide more choices in application setup. Total collapse limits are included for weld or hold.
- **Expanded quality monitoring limits** to identify both "suspect" and "reject" parts.
- **Built-in digital amplitude control** - for fine tuning of critical applications, because amplitude is the most important variable in ultrasonic welding. The setting has a range of 10% to 100%.
- **True alarm messages** for ease of troubleshooting, with links to additional information.
- **Self-diagnostics and monitoring** - visual, audible, and logic output alarms.
- **Built-in frequency and memory bargraph diagnostics** for simplified troubleshooting of the converter/booster/ horn stack.
- **Nonvolatile storage of cycle parameters.**
- **Alarm and cycle counters** are built in for tracking production; works via a real time clock.
- **Built-in ground detect** with scrub time to increase tooling and converter life in cut and seal applications.
- **Choice of language** for message display and printout—English, French, German, Italian, or Spanish—for ease of use in worldwide operations and multilingual workplaces.
- **Sixteen nameable presets** for ease of setup and changeover of applications.
- **Selectable pretriggering** — including pretrigger by distance.
- **Printing capability** - Provides a record for future comparison and validation. Printout of last 50 cycle weld history. Power, frequency, amplitude, distance, velocity, and force graphs can be printed. Includes drivers for ESC/P and HPL and ASCII output data.
- **Password protection feature** for lock-out of unauthorized process changes once the equipment is set up for a specific application.
- **Data management** — RS232 serial port provided for terminal, CompuWeld, or ASCII weld data. ASCII output data available in comma, space, and tab separated formats
- **Optional terminal** for ease of setup and cycle information display.

Power Supply

- **Line / Load Regulation** - Corrects for variations due to power line fluctuations and varying load conditions through Branson's patented closed-loop amplitude control. Output amplitude is maintained with a variation of only ± 2% with line voltage fluctuations of ±10%, regardless of load. It ensures constant power in welding, and provides greater weld consistency and reliability.
- **Autotune plus Memory (AT/M)** - Provides fully-automatic tuning in a range of ± 500 Hz centered around 19.950 kHz for 20 kHz horns, ± 750 Hz centered around 30 kHz for 30 kHz horns, and ± 1000 Hz around 39.900 kHz for 40 kHz horns, and stores horn frequency at the end of each weld.
- **Selectable Starting Ramp** - Four selectable start rates—10, 35, 80, 105 milliseconds—to accommodate starting characteristics of a wide range of horns. This feature makes it easier to start more difficult horns or enables faster cycle rates.
- **Auto Seek** automatically measures stack frequency and stores it in memory. Four selectable Auto Seek choices are available:
  1. Externally with automation controller
  2. Depressing "test" switch
  3. By once/minute timer to track heating, cooling, and other effects
  4. Post weld seek.
- **System Protection Monitor (SPM)** Five levels of power supply protection are provided: 1) phasing, 2) over voltage, 3) over current, 4) over temperature, and 5) power. The benefits of this circuitry are to avoid equipment failures, and to provide greater weld accuracy and repeatability.

2000 SERIES PRODUCT/PERFORMANCE ENHANCEMENTS

The following chart gives a comparison of the new 2000d/aed system with 900 Series products. Benefits of the new features are highlighted.

900MA/AES	2000d/aed	Benefits
Power levels:	*Increased power levels:*	
20 kHz - 1000, 2000, 3000 Watts	20 kHz - increased to 1100, 2200, 3300 Watts	Higher available power for faster weld cycles
40 kHz - 700 Watts	40 kHz - increased to 400, 800 Watts	Higher power available for faster weld cycles
	30 kHz - new frequency, 1500 Watts	Higher power at higher frequencies; expands application range for delicate parts.
Single line VF display	Four-line VF display	More information visible; easier setup
Printing: setup and single line data	Printing: expanded setup and single line data	Easier setup and troubleshooting
Power, velocity, and force graphs	Power, velocity, force, frequency, amplitude, and distance graphs	Easier troubleshooting
20 presets	16 nameable presets	Ease of setup
Process alarm limits	Part monitoring limits: suspect and reject	Enhanced process monitoring
Alarm messages	Additional alarm messages, with specific support support information	More specific information for easier trouble-shooting and corrective action
Optional amplitude stepping	Built-in patented amplitude stepping	Increased strength of welds, control of flash, reduction of particulate, reduced residual stresses.
Weld by distance (absolute, collapse)	Distance mode: absolute, collapse, step amplitude at a distance	Enhanced use of distance function, enhanced process control
Trigger force setting thru interface	Trigger force setting through interface	Helps ensure weld consistency
Multi-turn down speed control	Single-turn downspeed control with setscrew lock	Easier to set up, easier to duplicate prior setup
	Digital amplitude setting with range of 10-100%	Fine tuning of critical applications
	Single 20 kHz converter at all power levels with 20% higher converter output amplitude	Eliminates setup errors, faster weld cycles
	Reporting of weld force	Additional weld data
	Built in force and pressure calibration capability	Satisfies agency requirements (e.g., FDA)
	User configurable password protection	Lock out unauthorized process changes
	Choice of language for message display and printout	Ease of use in worldwide operations and multilingual workplaces.
	External selection of presets via PLC	More precise setup and limits; manufacturing flexibility
	ASCII data output	External data logging and graphing

- **Automation interface** is available for direct hookup with PLCs and PCs. Required automation I/O's are provided through a 24V DC logic interface. Signals include weld on, general alarm, and external reset. Fifteen externally selectable presets are available. Systems without an actuator may be operated via a simplified interface to a PLC.

Actuator

- **Linear optical encoder** measures weld "distance" enabling welding by specific part collapse (meltdown), or to a finished part height (absolute). Resolution on the encoder is 0.0001 inch.
- A force transducer provides digital setting of the Dynamic Trigger and allows the user to print out force data and graphs for performance evaluation and troubleshooting.

- Pressure transducer accurately monitors and displays air pressure and allows accurate and repeatable setting of weld force.
- **A single 20 kHz converter** is used for all 20 kHz power supplies. This converter produces 20% higher output amplitude for faster weld cycles.
- **Converter cooling** - Cooling air is directed into the converter during each operating cycle.
- **Five air cylinder** sizes are available for better control of clamp force. Sizes include: 1.5, 2.0, 2.5, 3.0, and 3.25 inches.
- **Custom single-turn flow control** provides for more accurate setting of velocity/downspeed, and easier resetting during application changeover.
- **Stroke indicator**
- **Calibratable pressure gauge**
- **"Horn down"** function enables ease of horn/fixture alignment.

BRANSON

SPECIFICATIONS

Most units are CE compliant, and comply with FCC rules and regulations governing radio frequency interference. Contact Branson, Danbury, for information.

2000d Power Supply	*20:1.1*	*20:2.2*	*20:3.3*	*30:1.5*	*40:0.4*	*40:0.8*
Output power:	1100 Watts	2200 Watts	3300 Watts	1500 Watts	400 Watts	800 Watts
Line voltage:	117 V AC * 50/60 Hz, 1ph.	200-240 V AC 50/60 Hz, 1ph.	200-240 V AC 50/60 Hz, 1ph.	117 V AC * 50/60 Hz, 1ph.	117 V AC * 50/60 Hz, 1ph	117 V AC * 50/60 Hz, 1ph
Max. current:	14 amps max.	14 amps max.	17 amps max.	20 amps max.	6 amps max	12 amps max.
Receptacle required	NEMA 5-15R	NEMA L6-20R	NEMA L6-20R	NEMA 5-20R	NEMA 5-15R	NEMA 5-15R
Frequency	20 kHz	20 kHz	20 kHz	30 kHz	40 kHz	40 kHz
Max. cycle rate:	80 cpm **					
Ambient temp. range:	41-122° F (5-50°C)					
External inputs/outputs:	9-pin start connector; 44-pin user I/O connector					

Actuator Model	*aed1.5*	*aed2.0*	*aed2.5*	*aed3.0*	*aed3.2*
Max. clamp force on part (at 100 psig/ 690 kPa)	140 lbs. 623 N	270 lbs. 1.2 kN	440 lbs. 1.96 kN	650 lbs. 2.89 kN	770 lbs. 3.42 kN
Dynamic Triggering range:	5-140 lbf. 22.24-623 N	5-270 lbf. 22.24 N-1.2 k N	5-440 lbf 22.24 N-1.96 kN	5-636 lbf. 22.24 N-2.83 kN	5-725 lbf. 22.24 N-3.22 k N
Dynamic Follow-through range:	5-140 lbf. 22.24-623 N	5-270 lbf. 22.24 N-1.2 kN	5-400 lbf 22.24 N-1.78 kN	5-400 lbf. 22.24 N-1.78 kN	5 lbf. -400 lbf. 22.24 N-1.78 kN
Stroke length:	4" (101.6 mm)				
Pneumatic requirement:	Clean (5 micron, filtered), dry, non-lubricated air at 100 psi (690 kPa)				

* 200-240 V AC optional.
** Application dependent.

All specifications subject to change without notice. All dimensions are nominal.

AVAILABLE OPTIONS

- **Leveling fixture** - base-mounted plate for horn/fixture alignment.
- **Dump valve** - for release of cylinder pressure for ease of setup.
- **Solid mount boosters**
- **Longer columns** - 4' to 6' lengths
- **Printer with cable** - printing of setup and cycle information for comparison and troubleshooting.
- **Terminal with cable** - for screen-driven setup
- **Ground detect cable**

Note: All sales shall be subject to the Supplier's terms and conditions of sale as described in Branson's quotations and sales contracts.

REGIONAL TECHNICAL CENTERS

Headquarters:	Toll free: 888-BUC-JOIN (888-282-5646)	
Boston:	781-938-8168	Fax: 781-935-0535
Chicago:	847 229 0800	Fax: 847 229 0861
Atlanta:	770-962-2111	Fax: 770-962-3720
Los Angeles:	909-305-2080	Fax: 909-305-2060
Dallas:	972-484-9228	Fax: 972-484-9976
Detroit (Automotive):	248-299-0400	Fax: 248-299-9343
Rochester, NY:	585-624-8000	Fax: 585-624-1262
Toronto, Canada:	905-201-4633	Fax: 905-201-4637
Mexico City (Groupo Stevi):	011-52-555-670-4470	Fax: 011-52-555-670-7885

WARRANTY

The Branson 2000 Series d/aed ultrasonic assembly systems carry a three-year warranty on materials or workmanship. Note: This warranty applies to equipment purchased and operated in North America. For warranty information on units purchased and/or operated outside the U.S. contact your local representative.

CE

DNV Certification, Inc. USA

DNV MSC The Netherlands Accredited by the RvA

ISO 9001 REGISTERED FIRM

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